COTTON IRRIGATION

Cotton yields and quality can be improved significantly by irrigation when drought occurs during late June, July and August particularly on coarse textured, sandy land. During peak blooming cotton will use about 0.3-0.4 inch of water per day. Irrigated cotton yields have been from 0 to more than 800 lbs. lint/A greater than non-irrigated yields with the most frequently reported increases being in the 200 to 400 lbs./A range. The following procedure is suggested for 900 to 1100 lbs./A yields: Prior to first bloom irrigate with 0.75-1.00 inch of water whenever drought stress wilting of plants is observed around noon. After first bloom, irrigate as needed to supply crop the quantities of water listed below. Rain gauges should be used to measure the water received from rain and the amount supplied by irrigation.

Period	Quantity/Week	Quantity/Day
Wk. beginning at 1st bloom	1"	0.15"
2nd wk. after 1st bloom	1 1/2"	0.22"
3rd wk. after 1st bloom	2"	0.30"
4th wk. after 1st bloom	2"	0.30"
5th wk. after 1st bloom	1 1/2"	0.22"
6th wk. after 1st bloom	1 1/2"	0.22"
7th wk. after 1st bloom	1"	0.15"

Examine the crop during the 7th week to determine if irrigation should be continued.

Irrigation intervals can be determined by dividing the quantity/day for a period into 1/2 to 2/3 the available moisture holding capacity of the upper 2 feet of soil in fields. For example, if the available moisture capacity of the soil is 0.7" per foot and the quantity/day is 0.3", the interval between irrigations or following rain that brings soil moisture to field capacity would be 0.66% x 2 ft x 0.7"/ft. divided by 0.3"/day = 3.08 or 3 days.

Intervals for most of the season will be 3-4 days for coarse textured sand, 4-6 days for more productive loamy sand and sandy loam, and 5-8 days for fine textured sandy loam or "clay". A 4-6 day interval will fit a large majority of the situations.

Experience over the past 8 years soundly indicates 900 to 1100 pounds/acre or better yields can be expected with the above 7 week irrigation scheduling technique. However, there have been several reports across the years and many, including myself, feel that more water is needed for super high, 3 bale plus, yields. Such yields were reported from several locations in 1984. Rainfall--irrigation-yield histories from 2 locations with water supplies of 14.5" and 16.4" during the first 7 and 8 weeks of blooming in 1984 show yields of 1683 and 1358 pounds lint/acre respectively.

Those with intensely managed production programs that are already harvesting 2 bale yields who are striving for super high 3 bale plus yields on part of their crop may want to increase the amount of water supplied by using their rain gauges and irrigating to provide the quantities of water listed below on a trial

basis. This will provide 4 more inches during the 7 week period than the quantities suggested for "2" bale yields. Continue applying 0.75-1.00 inch of water at the first sign of drought stress prior to first bloom. It should be remembered that abundant moisture magnifies vegetative growth problems when excessive nitrogen is available and/or insect control is insufficient.

Period	Quantity/Week	Quantity/Day
Wk. beginning at First bloom	1.5"	0.22"
2nd. Wk. after First bloom	1.5"	0.22"
3rd. Wk. after First bloom	2.5"	0.36"
4th. Wk. after First bloom	2.5"	0.36"
5th. Wk. after First bloom	2.5"	0.36"
6th. Wk. after First bloom	2.0"	0.30"
7th. Wk. after First bloom	2.0"	0.30"

Weekly quantities should be increased to compensate for runoff. Examine the crop during the 8th. week of blooming to determine if irrigation should be continued.

June 18, 1986
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VINEYARD WATER MANAGEMENT BY THE DIRECT MEASUREMENT OF PLANT-WATER STRESS

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INTRODUCTION

Water is the most important "nutrient" for the growth of a grape vine. Its availability is crucial to both the quantity and quality of the crop. Water has such importance that, until recently, its application was routinely excessive due to the fact that the result of too much water is minor compared to that of an inadequate application. The advent of drip irrigation and the increasing cost of water have combined to produce problems due to over irrigation that are substantial enough to warrant consideration. The increases in energy costs have made irrigation expensive and provided an economic incentive to improve irrigation efficiency. One popular method of increasing irrigation efficiency is the use of the drip/trickle method. The ability of a drip irrigation system to maintain soil water at an optimum level can produce improvements in growth, however, some undesirable effects on the development of the fruit may occur. The same conditions that produce more foliage growth can produce an exceptionally tight cluster that may be more susceptible to Botrytis damage.

The problem facing the viticulturalist is the balance between prevention of the economic and cultural problems of over irrigation with the obvious penalties of inadequate water application. The problem could best be managed by utilizing a method of monitoring plant water stress that is both sensitive to the condition of the plant and practical for use in the field. The water budget or Et scheduling is entirely indirect and must use extensive verification by some other method of plant stress monitoring to be truly accurate. Measurement of soil water with a neutron probe, tensiometer or resistance block is an established method but is still less direct in that the grower must estimate the soil moisture content that will result in plant stress. The direct measurement of leaf water status is most commonly done with a pressure chamber to determine leaf water potential. This can be quite accurate but must be done at sunrise. A device known as a Porometer is available that will measure the transpiration rate of a small section of a leaf in the field. Water stress first shows as a reduction in transpiration rate so the porometer can provide a direct measurement of stress in the vine. The porometer only measures transpiration on a small section of one leaf. The transpiration rate varies with the condition, age, and amount of sunlight on the leaf as well as its water status. Several measurements must be made of the leaves of a vine to determine its stress level. The porometer is a rather delicate device which requires careful handling and calibration. It is a research device that is not suitable for use in commercial viticulture.

The final method of plant water stress monitoring employed in this trial was Infrared Thermometry (IRT). The device used is a combination of sensors that measures leaf temperature and atmospheric conditions. Transpiration is an evaporative process which will reduce the temperature of the leaf. The IRT device measures the leaf temperature and compares it to a predicted temperature for a non-stressed leaf. A measured temperature higher than the predicted temperature indicates a reduction in transpiration due to water stress. One of the purposes of the experiment was to validate the use of the IRT method against the porometer. The IRT device is suitable for use by commercial viticulturalists in the field with minimal training in its operation. It would be a practical tool for irrigated vineyard management if it is capable of accurately determining the onset of plant water stress.

THE INFRARED THERMOMETRY METHOD FOR MEASURING PLANT WATER STRESS

The primary function of the plant leaf is the support of the photosynthetic process. The leaf must provide a supply of carbon dioxide to the cells containing the chlorophyll along with the water and exposure to light required by the process. The CO2 comes from the atmosphere and so the leaf must be open to the air in order to acquire it. Most of the CO2 enters through the stomata in the epidermis of the leaf through which water vapor also evaporates. The leaf has a mechanism to close the stomatal openings if the water content of the leaf decreases to the point where the leaf tissue would be damaged. This action reduces the water loss from the interior of the leaf but it also reduces the intake of CO2 and therefore, photosynthesis. The main physiological reason for irrigation is to prevent the water stress condition that will close off the supply of CO2 to the chlorophyll of the leaf which would reduce growth and yield.

Transpiration, the loss of water vapor from the leaf, is an evaporative process which means energy is absorbed as the water vaporizes in the leaf. This loss of energy produces a reduction in temperature of the leaf compared to the air temperature that is proportional to the amount of transpiration. If the transpiration rate of an unstressed plant were constant, the measurement of the difference between leaf and air temperature would be simple but that is not the case. The rate of water loss is subject to the same physical laws that control water evaporation. It is affected by the ambient air temperature, the humidity and the amount of wind. A cool, moist day will result in little transpiration and therefore little difference between the leaf temperature and that of the surrounding air. In contrast, a temperature of 100 F with relative humidity below 20% will produce a rate of transpiration that can drop the temperature of an unstressed leaf to less than 90 F. The leaf temperature of an unstressed vine is potentially predictable. There are two sets of factors that will determine it:

1. Atmospheric: The combination of air temperature and humidity which can be used to calculate the vapor pressure deficit of the air.

2. Crop: The characteristics of the particular crop or variety such as its leaf color, reflectivity and surface properties. These must be measured and factored into the calculation for each type of plant.

Once the potential minimum temperature of a leaf can be calculated for a set of conditions and for a particular variety then the actual leaf temperature can be measured and compared with the predicted value to measure stress. A ratio or index of the actual, measure temperature to the predicted value may be calculated to indicate the degree of stress.

This method has been studied by various researchers for nearly 30 years with only limited application to commercial agriculture. Recently advances in the technique have been made and a measuring device with a combination of the appropriate sensors to collect the required data along with a microprocessor and memory to process it has become available. This device, called the "Scheduler" was provided for this project by the Standard Oil Engineered Materials Co. of Cleveland OH.

IRT MEASUREMENTS IN THE VINEYARD

The collection of data for the determination of water stress in the vines was found to be subject to a variety of constraints. The values obtained were useful for evaluating stress as long as the following conditions were observed:

1. The data should be taken from one hour prior to two hours past solar noon. This is the period of maximum transpiration and the leaves have the most exposure to sunlight.

2. The operator should point the instrument away from the direction of the sun to expose the infrared sensor to the greatest percentage of sunlit leaves and to prevent direct sunlight from falling on the temperature sensor of the device.

3. The operator should stand several meters away from the vine so that the area of measurement will be large enough to integrate temperatures from several leaves but not include the soil surface or the sky.

4. Care must be taken to ensure that the temperature of the device is close to that of the air since the infrared sensor only measures the difference between the surface at which it is pointed and its own temperature.

5. At least 10 individual measurements were taken at each plot site and averaged. This average value was reported as the reading for that plot on that date.

6. The data reported here can be used to illustrate relative stress among several points measured at about the same time. Changing weather conditions from day to day would cause the stress index numbers to shift while maintaining the relative differences. Some of this variation due to weather may be eliminated with new algorithms for the varieties that may be result from the data of this experiment.

EXPERIMENTAL DESIGN

Chenin blanc stress trial - 1986
This experiment was only a part of a larger project with the goal of evaluating the effects on yield of a short, intentional water stress to reduce the susceptibility of the crop to Botrytis just prior to harvest. The results and conclusions discussed here are concerned with the measurement of the level of plant stress due to the cutoff of irrigation water at various times.

The vines were mature Chenin blanc that had been irrigated by a drip system for 3 years prior to the experiment. Four different periods of stress were to be imposed on four replications each plus a control that was irrigated every day. The treatments received the same amount as the control except for the period that the system was turned off to create the stress. The treatments were designated A through E and are shown below with the stress period for which the irrigation was withheld:

A. Irrigation off from bloom to the beginning of rapid berry enlargement at which time irrigation resumed at 50% of estimated Et.

B. Irrigation off from bloom to the beginning of rapid berry enlargement at which time normal irrigation resumed for the rest of the season.

C. Irrigation normal to the beginning of rapid berry enlargement and then off until maturity.

D. Irrigation off through bloom set and then normal for the rest of the season.

E. Control, irrigation daily with the estimated Et of the crop as calculated from CIMIS information.

These treatments provided considerable stress as measured by both the IRT "Scheduler" and the porometer. Treatment "C" was particularly stressed late in the season. The applications and timing of the irrigations are shown in the graph titled WATER APPLICATIONS, CHENIN BL. 1986. The irrigations prior to and following the treatment periods were all the same as the control.

Thompson Seedless Irrigation Scheduling - 1987
The trials carried out in this past season with the IRT device used a modification of the method that is more adaptable to commercial viticulture. The unstressed, index vines used as a reference or control treatment were designated the "Cool Index" or CI. Irrigations of both a drip and a sprinkler irrigated vineyard of Thompson Seedless were initiated when the actual measured value of the vines in the plots reached some predetermined increase in stress level above that of the adjacent CI plot, i.e. CI+2 or CI+5. This method reduces the effect of weather changes on the irrigation decision although extremes of temperature and humidity will still affect the Crop Water Stress Index values from the device including the CI index.

The drip irrigated vineyard was divided into four treatment; the cool index, CI and three levels of stress, CI+1, CI+3, and CI+5. The measurements for these plots was made on three different sets of five vines for each treatment at

least once per week. After the measurements, the average CI was calculated and compared to the average stress index numbers from the stress treatments. If, for example, the average for the CI+3 plots was less than three CWSI units more than the CI for that date then the irrigation system was turned off until the measured stress values were more than the CI number plus 3. Once the plot exceeded its target, the CI+3, the drip system was turned back on until the measured values dropped back down to near that of the CI. The sprinkler irrigated trial was conducted in the same fashion as the drip except that there were only two stress levels, CI+2 and CI+5, in addition to the CI. The sprinklers were run every 7 to 10 days and the system in each of the treatments was cutoff in the same manner as the drip trial.

Grape Variety Trial - 1987

A second experiment on vines in 1987 was designed to test the differences in varietal response to the measurements made with the IRT method. There is a block planting at CSUF that contains most of common grape varieties and 18 were selected from both wine and table types for this experiment. The choice of varieties was made to include both large leafed, vigorous vines and those varieties that have naturally smaller, less dense canopies. All varieties were drip irrigated and were never stressed. The measurements were taken within the same hour each week for five weeks. The varieties along with the code letters used on the graphs are listed below:

Wine Grapes
CS - Cabernet Sauvignion
Ch - Chardonney
FC - French Collombard
ER - Emerald Reisling
CB - Chenin blanc
Mu - Muscat
PS - Petit Sirah
Ro - Royalty
SB - Sauvignion blanc
PN - Pinot Noir
Zi - Zinfandel

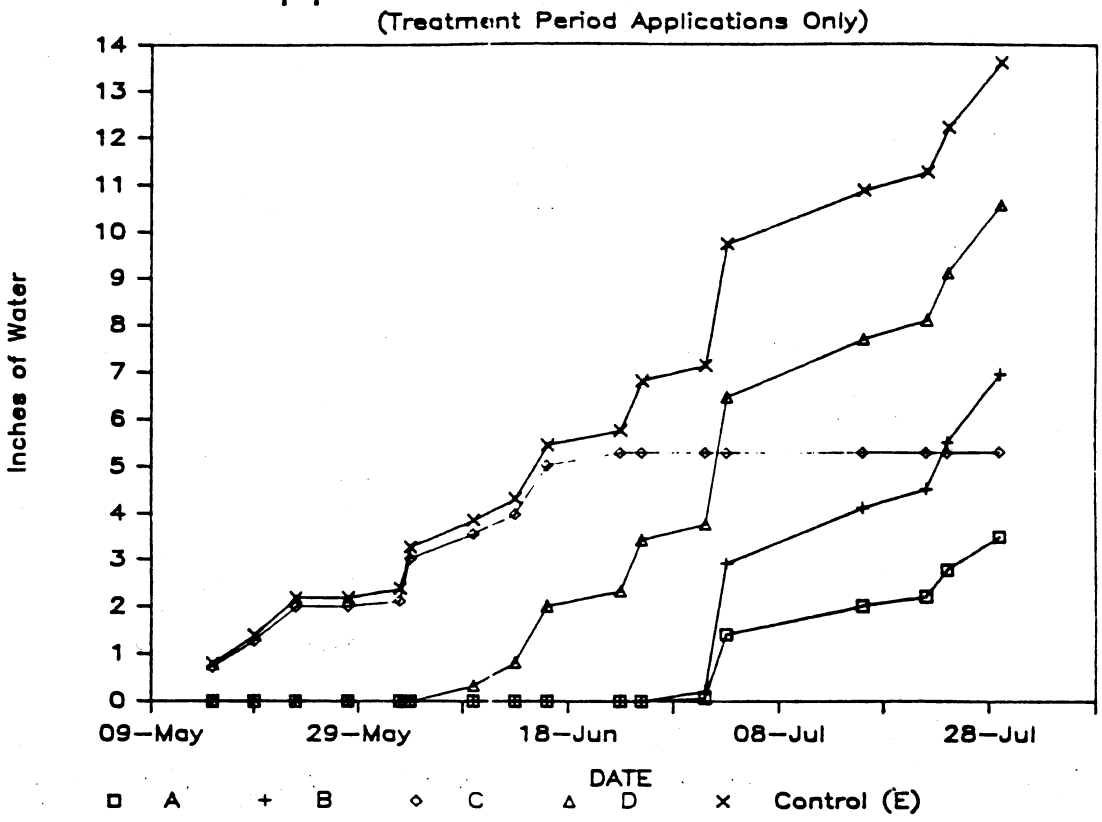
Table Grapes
Ca - Calmeria
Em - Emporer
Co - Concord
Ri - Ribier
TS - Thompson Seedless
Pe - Perlette
FT - Flame Tokay

EXPERIMENTAL RESULTS

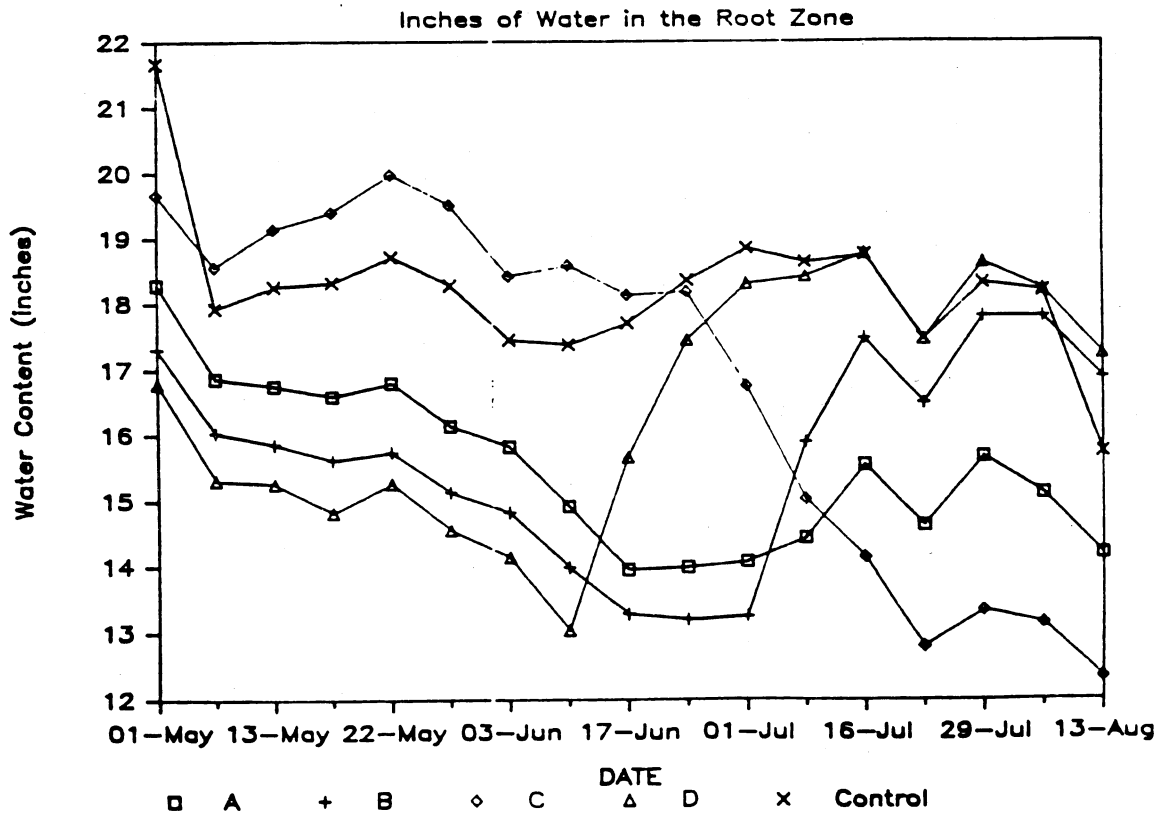
Chenin blanc Stress Trial - 1986

The results of the data collection for the purpose of detecting and quantifying the plant water stress showed relatively good correlation among the methods used. The water applications (WATER APPLICATIONS, CHENIN BL. 1986) were reflected quite well by the data for soil moisture content taken by the neutron probe the following week (ROOT ZONE WATER CONTENT). The various direct plant stress measurements each responded to the changes in water application in varying degrees. The leaf water potentials from the pressure chamber (not shown) were the least effective measure of plant stress. The data were consistent much of the time but did not always show a difference when there was an obvious stress imposed. The Porometer was quite consistent in its response to the imposed stress (Graph of TRANSPIRATION RATE). The changes in water application result in immediate changes in the rate of transpiration. There is

Water Applications, Chenin Blanc — 198E



ROOT ZONE WATER CONTENT



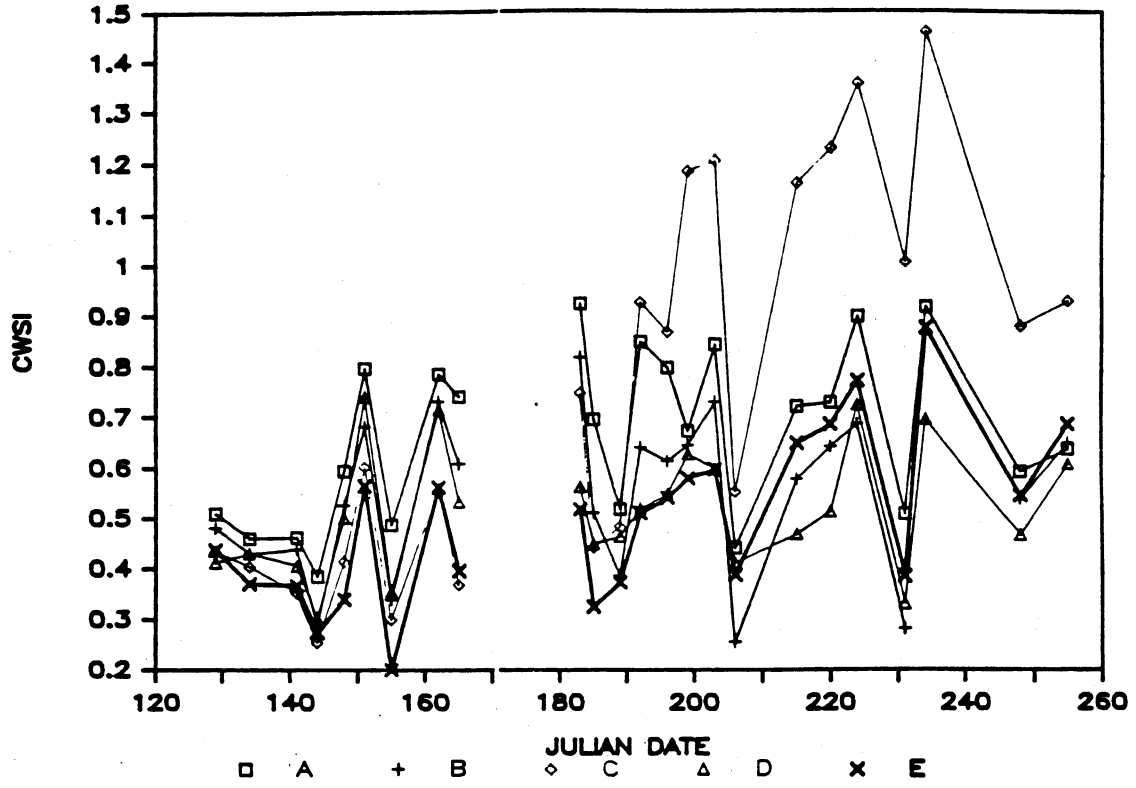
some fluctuation in the rates as shown on the graph, particularly early in the season and for the unstressed treatments but those fluctuations correspond quite well to changes in the weather. The hot, dry days produce high transpiration rates in all treatments contrasted with the lower rates for cooler weather. The unstressed treatments all responded in a similar fashion to the weather fluctuations. The stressed treatments, however, show not only a lower transpiration rate but also do not reflect the weather variations because there is little water available in the leaf to be transpired regardless of the weather. The IRT data (Graph of WATER STRESS INDEX, CHENIN BL. 1986) shows the stresses imposed on the vines as immediately as the porometer transpiration rates but in the opposite fashion. The porometer readings are reduced when the vines are stressed but the stress index of the "Scheduler" increases for the same condition. This index is a calculated value based on the difference between the actual plant leaf temperature and the predicted value of an unstressed leaf under the particular conditions of air temperature and humidity. An unstressed vine would have an index of 0 while a completely stressed vine would result in an index of 1. Values between 0 and 1 are proportional to the amount of stress. The stress index values from this experiment did not quite fall between 0 and 1 because the algorithm used to calculate the index was only an approximation. The results of this work have been used to refine the algorithm for more consistent index numbers. The IRT crop stress index is even more sensitive to the weather than is the porometer. The same cool, high humidity days that reduced the transpiration rate had the same effect on the calculated stress index. The SOHIO Scheduler used for the 1986 season was an early model that was upgraded with different programming for the 1987 season. The primary difference in the data between the two seasons is that the range of CWSI values was designed to go from 0 - 1 in the first year and from 0 - 10 for the second.

Thompson Seedless Irrigation Scheduling

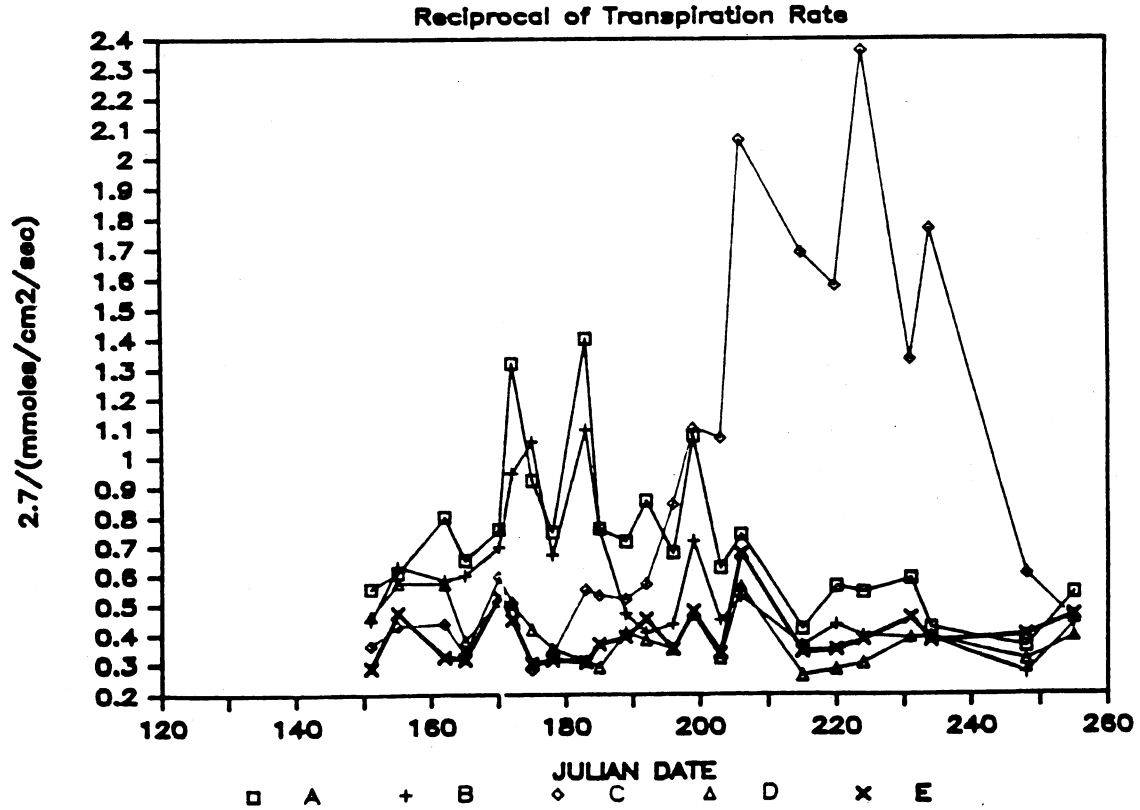
The scheduling of irrigations by limiting the vines to a certain stress level was more successful in the frequently irrigated drip plots than in the sprinkler irrigated vineyard. The middle of the 1987 season was also characterized by several periods of exceptionally cool weather which reduced the normal development of stress that would be expected during July and early August in the water deficient vines. All of the treatments in the drip trial were relatively equal until late June when only the CI treatment was left on (Thompson Seedless - Drip 87). After the initial development of stress the irrigations were restarted but the weather cooled at that point so the second stress period was very slow to develop and all of the stress values were reduced. the return of hot weather in early August produced differences in stress for the CI+3 and CI+5 treatments but the CI+1 apparently had sufficient water applied during the cool weeks to prevent stress later. The vines were harvested on August 12. The high stress (CI+5) had a significantly lower yield but the others were essentially equal to the unstressed (CI) treatment.

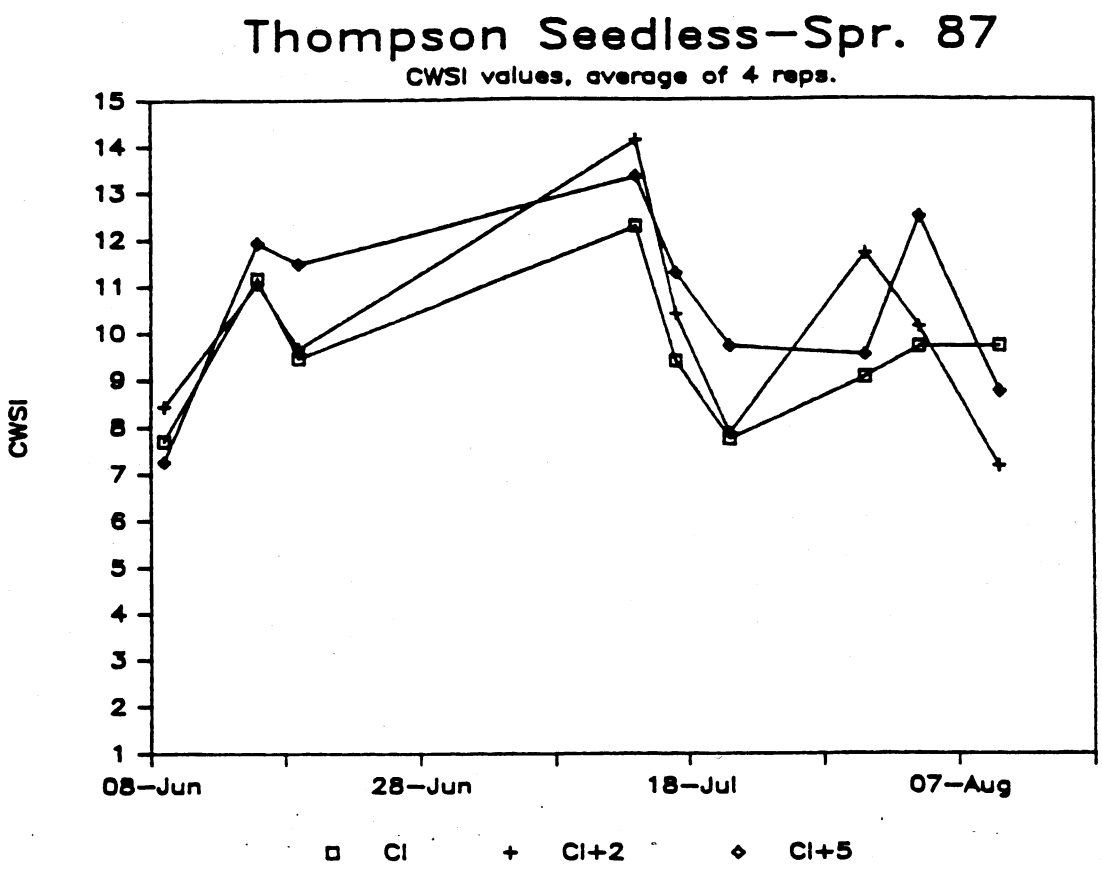
The sprinkler trial had the same weather problem that reduced all of the stress levels as was seen in the drip data with the additional complication of an infrequent irrigation schedule. The sprinklers could only be run on a 7 to 10 day interval to coordinate with the other cultural practices. The result was that it was not possible to prevent some stress even in the CI treatment and so there was never as much difference as anticipated between the treatments as with the drip trial. The harvest produced yields from the CI comparable to the

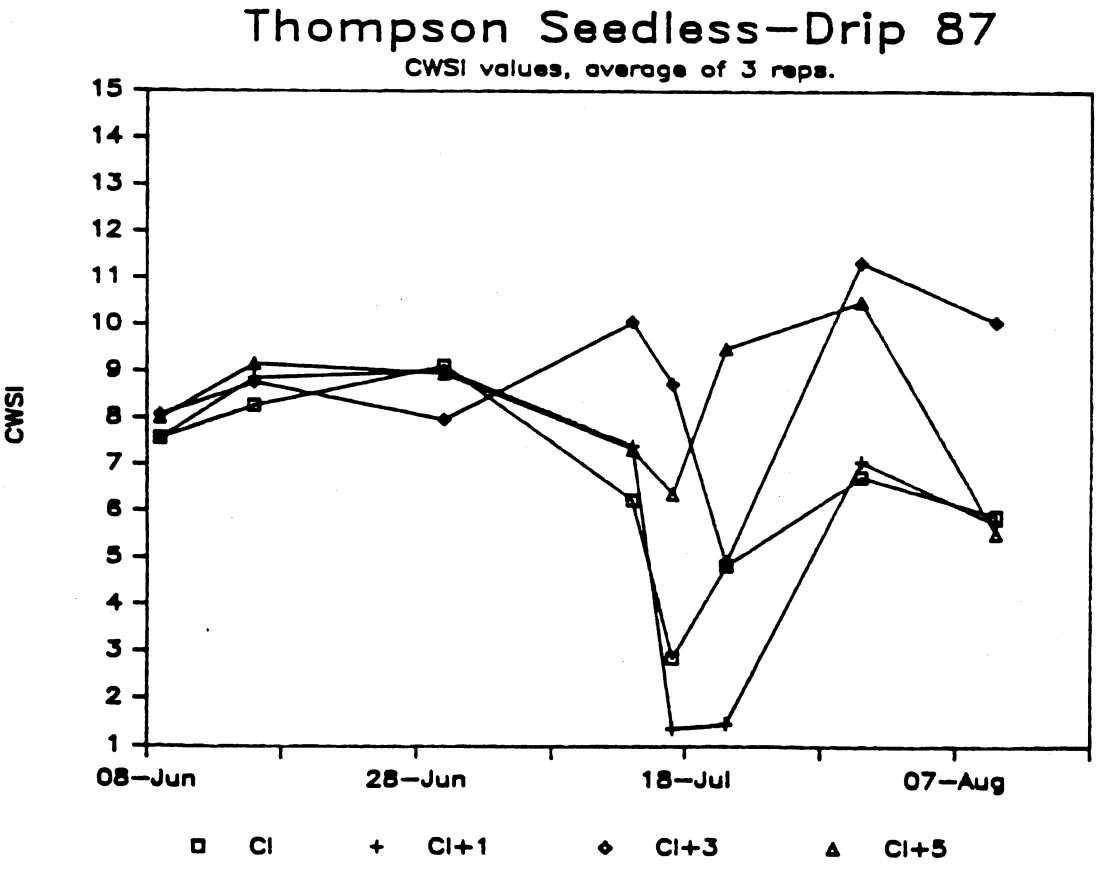
CWSI VALUES – CHENIN BLANC 1986

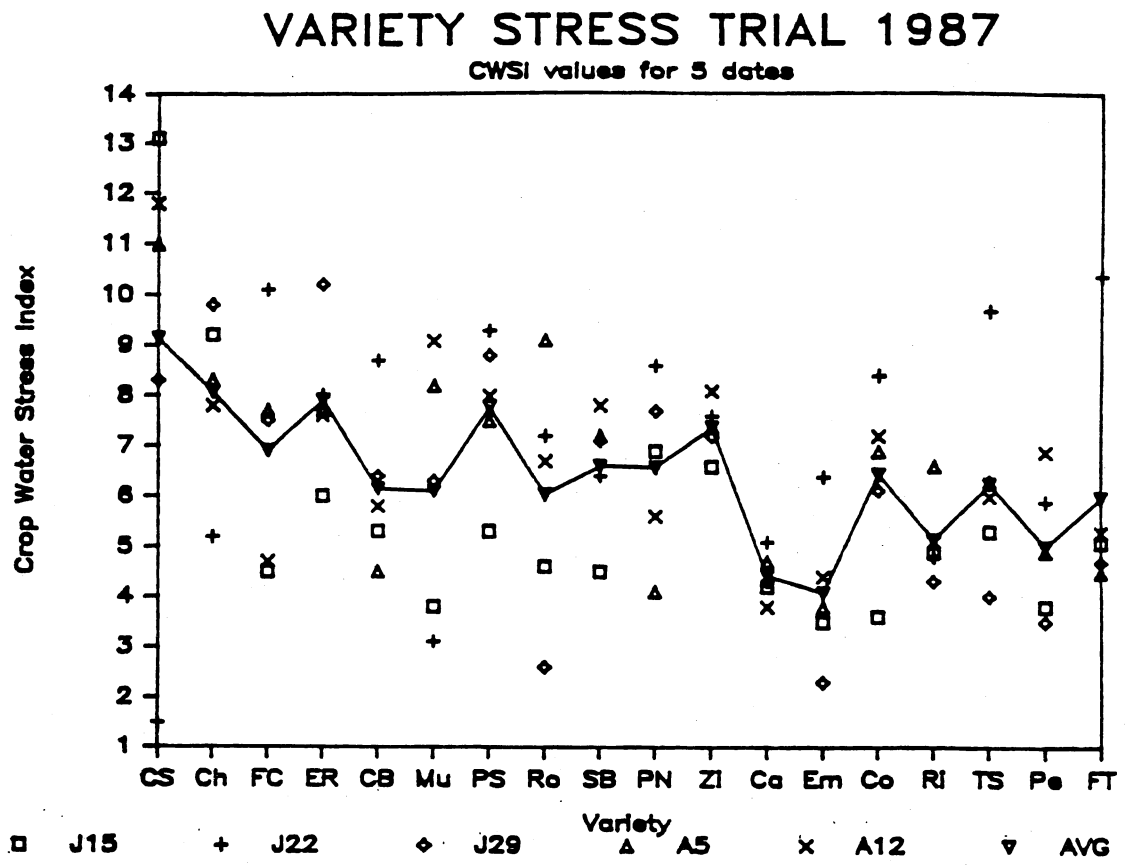


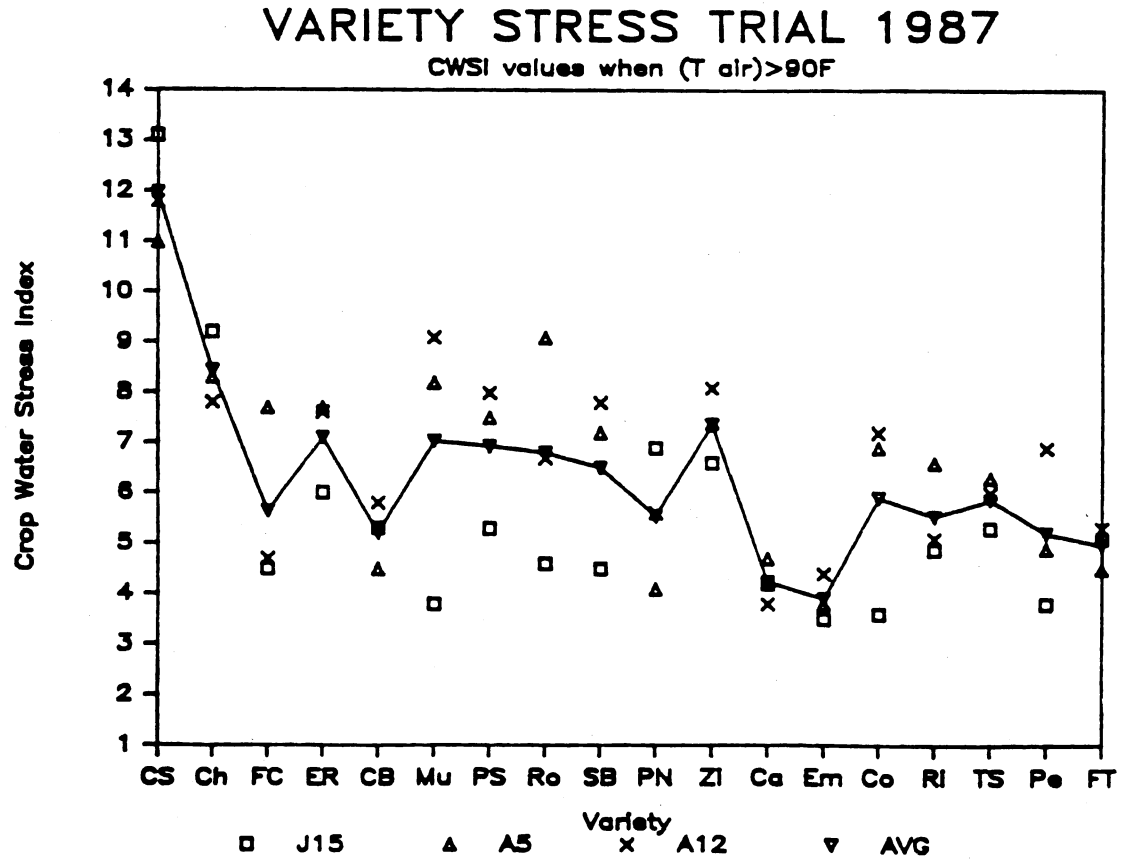
TRANSPIRATION – CHENIN BLANC 1986




Thompson Seedless—Spr. 87
CWSI values, average of 4 reps.
CWSI
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
08—Jun
28—Jun
18—Jul
07—Aug
Cl
Cl+2
Cl+5


Thompson Seedless—Drip 87
CWSI values, average of 3 reps.
CWSI
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
08—Jun
28—Jun
18—Jul
07—Aug
Cl
Cl+1
Cl+3
Cl+5


VARIETY STRESS TRIAL 1987
CWSI values for 5 dates
Crop Water Stress Index
14
13
12
11
10
9
8
7
6
5
4
3
2
1
CS Ch FC ER CB Mu PS Ro SB PN ZI Ca Em Co RI TS Pe FT
Variety
J15 J22 J29 A5 A12 AVG


VARIETY STRESS TRIAL 1987
CWSI values when (T air)>90F
Crop Water Stress Index
14
13
12
11
10
9
8
7
6
5
4
3
2
1
CS Ch FC ER CB Mu PS Ro SB PN ZI Ca Em Co RI TS Pe FT
Variety
J15 A5 A12 AVG

best of the drip vines but the stressed treatments were both significantly lower than the CI for the sprinkler trial.

Variety Comparison - 1987

The objective of the variety trial was to determine if there was a need to correct the algorithm used for grapes in the Scheduler for different grape varieties. The complete set of data (Variety Stress Trial 1987, CWSI values for 5 dates) indicates a considerable variation in values for the 18 grape varieties. Further inspection suggested that most of the extreme values except for the first variety to be read each day, Cabernet Sauvignion, were collected on the two sampling dates where the air temperature was less than 90F. It may be that some varieties react differently to the cool temperatures or possibly the IRT method is not as consistent at the lower temperatures. The second data figure (Water Stress Variety Trial 1987, CWSI values when T air > 90F) shows more consistent numbers and perhaps some differences among the varieties. The lowest of the CWSI's are generally from those varieties with large leaves and a thick, vigorous canopy, particularly in the table grape group. Those varieties are the ones that produced the most consistent CWSI values among the dates. There are several possible explanations for this including: 1. the vigorous vines have larger root systems that more efficiently supply soil water and reduce the stress level, or 2. the smaller leaves and thinner canopy of the less vigorous vines produces a less consistent reading by the Scheduler. In either case, the varietal differences are small and should not materially affect the use of the Scheduler for commercial, viticultural use. It was very apparent that the greatest variation in the CWSI values was for the Cabernet Sauvignion, the first plot to be measured each day. The Scheduler used in this experiment was and older model that required a short time to adjust to field conditions so the values for the first variety may not always be accurate.

CONCLUSIONS REGARDING THE MONITORING OF WATER STRESS WITH THE IRT METHOD

The conclusions that can be drawn from all of the data taken in this experiment are numerous and related to many things beyond the measurement of stress for vine management. The results that are reported here are primarily concerned with the use of the IRT method of direct measurement of water stress compared to other, more traditional stress monitoring methods. These conclusions will therefore be limited to a discussion of the merits of the IRT method related to the characteristics of the other methods.

The Infrared Thermometry device as represented by the "Scheduler" developed by SOHIO and any other similar combination of sensors is a very sensitive and yet practical means of determining the water stress status of a crop such as vines.

The neutron probe while quite accurate in its evaluation of soil moisture content did not provide any measurement of stress. Considerably more work would be required to correlate the soil water content to stress level in the vines and once the calibration was done, it would be accurate for this particular soil only and would also require that the device be placed in the same position in the vine root zone and drip system wetting pattern to provide consistent data.

Measurement of leaf water potential with the pressure chamber is an established method but one with severe restrictions. The accepted procedure requires the readings to be taken at dawn before the transpiration gradient of water potential is created by the plant/atmosphere system. The short period of time available for readings and the fact that the bulky equipment requires considerable time to measure each leaf seriously limits the amount of data that can be collected each day. The poor correlation of the pressure chamber data in this trial was certainly due to the fact that it took 90 minutes to read all of the plots. By the end of the collection period, the sun had risen to the point that there was sufficient transpiration to increase the leaf water potential above its "resting point" at dawn.

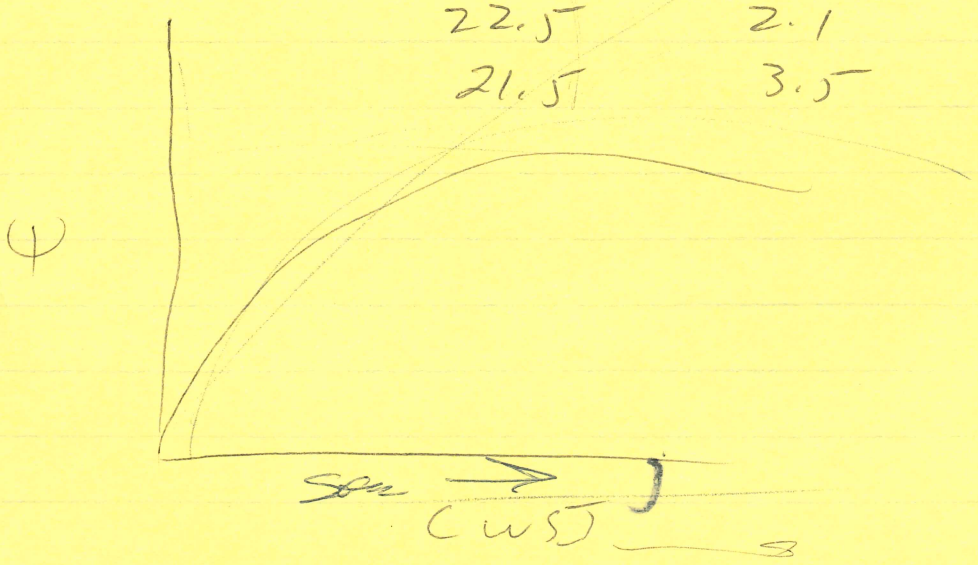
The porometer could successfully monitor plant stress by the reduction in transpiration rate with more sensitivity than the pressure chamber or neutron probe. It has several disadvantages that are sufficient to eliminate the porometer from consideration for commercial applications. The data collection is slow because several leaves must be measured to average the variations due to leaf age, condition and sunlight. The device is rather expensive (about $8000) and somewhat delicate. It requires regular servicing to dehydrate the desiccant each week to maintain the accuracy of the readings. It is an excellent example of research equipment that can be used in the field for work such as this experiment but it would not be a good choice for irrigation scheduling by a professional viticulturalist.

The IRT device is as sensitive to plant stress as the porometer while more simple to operate and maintain than the other devices discussed above. It is designed to operate under field conditions and to handle a number of plots or fields quickly. It is about half the cost of the porometer and requires only routine replacement or recharging of its batteries for service. The primary difficulty with its use on grapes in this experiment was the fact that the weather conditions affected the calculated crop stress index to the point where comparison of readings in a plot from one day to the next were not valid if there was a significant weather change. The relative differences were still there between stressed and unstressed vines on all but the coolest days. If a known, unstressed vine is used as a reference and the indexes for the vines in question for that date are compared with the reference vine then the IRT method can be used very well for stress management.

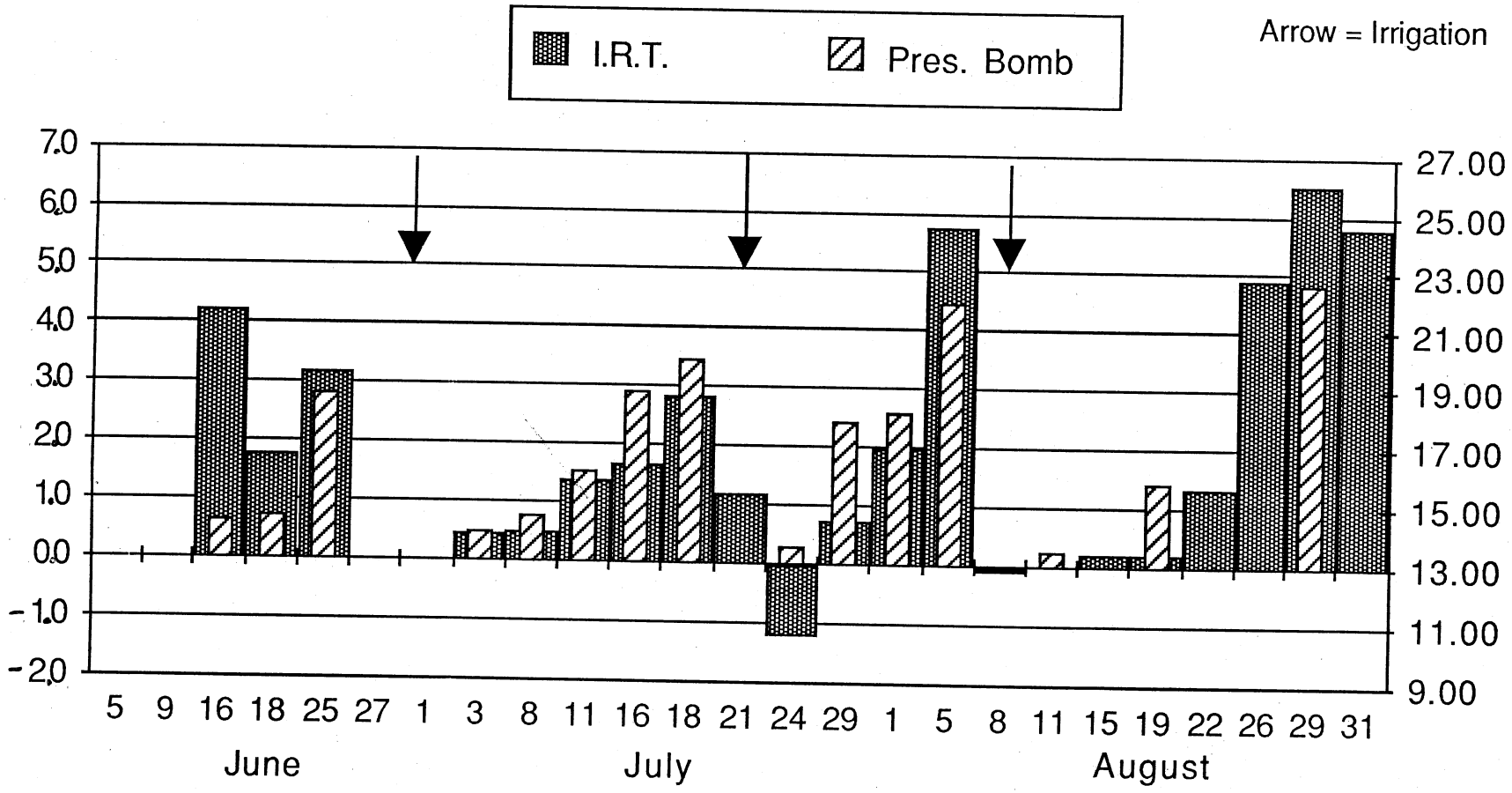
Fresno, Calif

CWSI	Cotton lint bales/Acre	Seed (~~lbs/Acre~~) (thousand lbs/Acre)
0.1	3.39	~~5.08~~ 5.074
0.3	3.22	4.717
0.5	2.73	4.214

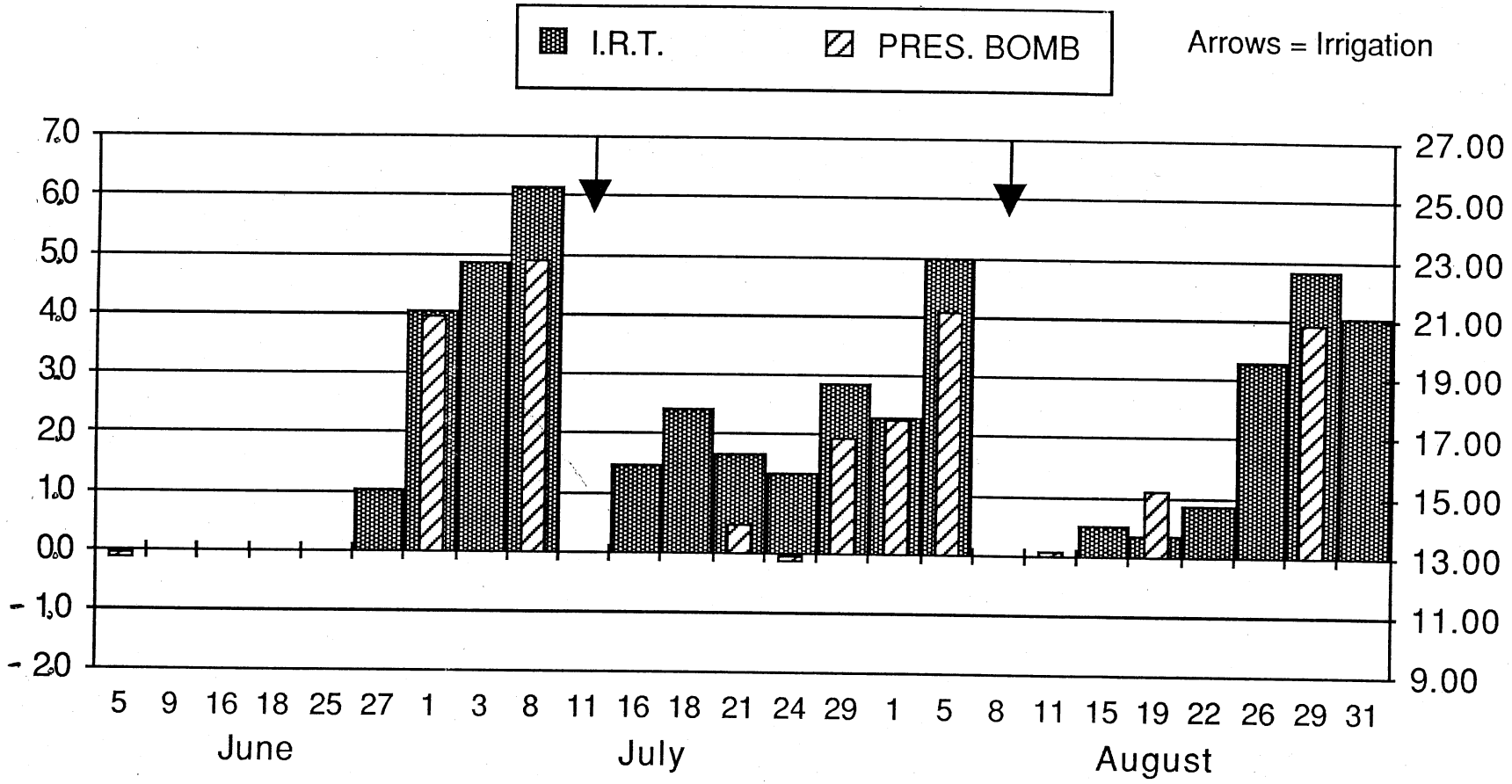
Average CWSI	Average Pressure Bomb ~~F~~ ~~Std~~	
−0.23	14.0	±
−0.06	14.9	± 1.7
0.05	15.9	± 2.4
0.15	16.1	2.7
0.25	17.9	2.1
0.35	19.1	1.9
0.45	21.2	1.3
0.54	21.7	2.4
0.64	22.5	2.1
0.75	21.5	3.5



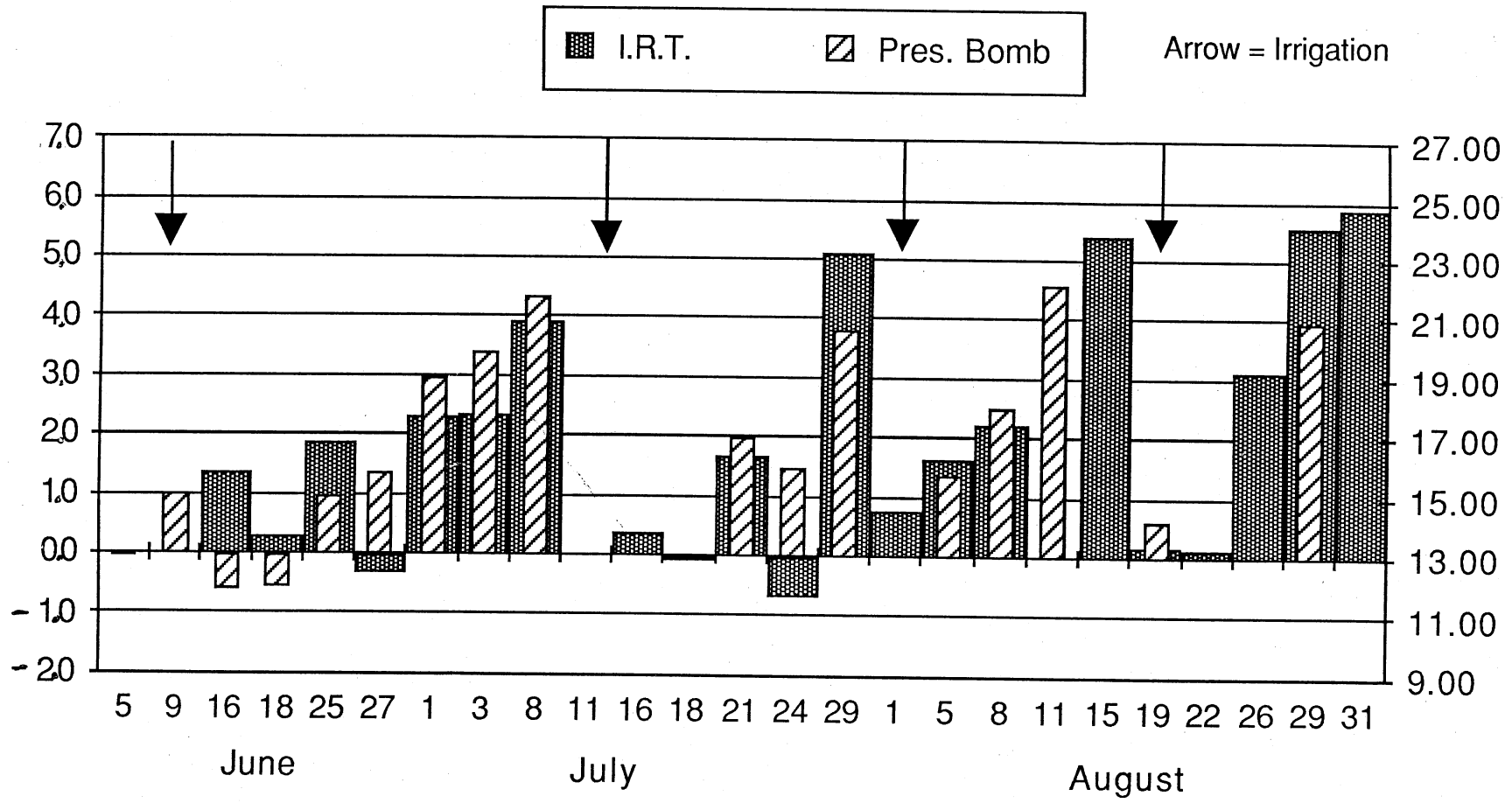
I.R.T. & Pressure Bomb Comparison
Medium Stress Treatment



I.R.T. & PRESSURE BOMB COMPARISON
HIGH STRESS TREATMENT



I.R.T. & Pressure Bomb Comparison
Low Stress Treatment



IRT Pressure Bomb Data Summary, WSFS 1986

			6/5	6/9	6/16	6/18	6/25	6/27	7/1	7/3	7/8	7/11	7/16	7/18	7/21	7/24	7/29	8/1	8/5	8/8	8/11	8/15	8/19	8/22	8/26	8/29	9/1
1	A	205								0.39	0.5		0	0.00	0.11	-0.16	0.46	0.05	0.16	0.21		0.55	0	-0.01	0.23	0.51	0.6
1	A	302								0.34	0.63		0.05	-0.25	0.25	0.01	0.38	0.07	0.21	0.26		0.65	0.09	0.05	0.46	0.59	0.7
1	A	409			0.07	0.04	0.19	0.09		0.07	0.28			0.01	0.15	-0.12	0.65	0.06	0.23	0.25		0.51	-0.02	-0.06	0.33	0.55	0.6
1	B	206								0.3	0.43		0.05	-0.13	0.13	-0.12	0.46	-0.03	0.16	0.07		0.43	0.01	-0.07	0.16	0.43	0.5
1	B	301								0.26	0.45		0.01	0.01	0.21	-0.08	0.46	0.1	0.14	0.34		0.7	0.06	0.16	0.46	0.68	0.6
1	B	408			0.21	0.05	0.2	-0.19		0.16	0.19			0.09	0.09	-0.09	0.63	0.09	0.09	0.08		0.43	-0.04	-0.03	0.28	0.5	0.4
1	C	204								0.25	0.39		0.06	0.03	0.16	0.02	0.61	0.18	0.21	0.37		0.61	0.01	0	0.28	0.61	0.7
1	C	303								0.13	0.44		0.07	-0.01	0.22	-0.01	0.34	0.12	0.14	0.23		0.53	0.05	0.08	0.35	0.6	0.6
1	C	407			0.13	0	0.17	0	0.23	0.22	0.23			0.17	0.20	-0.07	0.61	0.06	0.15	0.19		0.49	0.02	0	0.26	0.56	0.5
Averages			#####	#####	0.14	0.03	0.19	-0.03	0.23	0.24	0.39	#####	0.04	-0.01	0.17	-0.07	0.51	0.08	0.17	0.22	#####	0.54	0.02	0.01	0.31	0.56	###
2	A	209								0.12	0.02	0.11	0.26	0.39	0.19	-0.09	0.12	0.25	0.67	0		0.07	0.04	0.19	0.67	0.82	0.8
2	A	308								0.01	0.05	0.13	0.11	0.18	0.11	-0.14	0.11	0.18	0.5	0.12		-0.05	0	0.19	0.42	0.61	0.6
2	A	406				0.22	0.32			-0.05	-0.03	0.06	0.17	0.27	0.08	-0.18	-0.05	0.24	0.63	-0.09		-0.02	0.08	0.15	0.5	0.55	0.6
2	B	207								0.12	0.13	0.23	0.32	0.44	0.16	-0.18	0.04	0.2	0.53	0.03		0.07	-0.02	0.14	0.42	0.73	0.7
2	B	309								-0.02	-0.05	0.07	0.16	0.41	0.09	0.04	0.14	0.13	0.46	-0.05		-0.09	0	0.1	0.51	0.62	0.5
2	B	404			0.38	0.18			0	0.03	0.05	0.19	0.04	0.05	0.07	-0.14	0.06	0.24	0.61	-0.04		0.03	0.05	0.21	0.52	0.55	0.4
2	C	208								0.22	0.17	0.14	0.26	0.40	0.19	-0.21	0.05	0.17	0.54	0.06		0.07	0.05	0.09	0.47	0.75	0.7
2	C	307								0	0.09	0.18	0.13	0.37	0.11	0.02	0.2	0.25	0.7	-0.08		0.1	0.01	0.09	0.5	0.66	0.5
2	C	405			0.47	0.14				0	0.02	0.13	0.06	0.03	0.08	-0.22	0	0.14	0.57	-0.05		0.01	0	0.07	0.44	0.59	0.5
Averages			#####	#####	0.43	0.18	0.32	#####	0.00	0.05	0.05	0.14	0.17	0.28	0.12	-0.12	0.07	0.20	0.58	-0.01	#####	0.02	0.02	0.14	0.49	0.65	###
3	A	202								0.58	0.77		0.19	0.26	0.13	0.04	0.26	0.24	0.49	0		0.05	-0.04	0.11	0.23	0.45	0.4
3	A	304								0.53	0.65		0.31	0.32	0.14	0.11	0.33	0.24	0.57	0.03		0.09	0.03	0.04	0.34	0.49	0.5
3	A	401						0.21	0.4	0.4	0.52		0.09	0.10	0.09	0.06	0.25	0.24	0.61	0		0	0.05	0.27	0.44	0.53	0.3
3	B	201								0.57	0.6		0.06	0.20	0.14	0.16	0.34	0.16	0.28				0.04	0.16	0.14	0.35	0.4
3	B	306								0.46	0.62		0.14	0.26	0.13	0.21	0.26	0.22	0.37	0.02		0	-0.02	-0.08	0.26	0.48	0.5
3	B	402						0.03	0.41	0.39	0.52		0.08	0.24	0.15	0.16	0.12	0.18	0.48	0		0.02	0.01	0.03	0.39	0.53	0.4
3	C	203								0.53	0.71		0.19	0.26	0.24	0.16	0.23	0.23	0.51	-0.09		0.04	-0.03	0.03	0.3	0.51	0.4
3	C	305								0.55	0.68		0.21	0.34	0.18	0.12	0.5	0.22	0.45	0.06		0.14	0.14	0.06	0.48	0.5	0.5
3	C	403						0.07		0.39	0.49		0.08	0.21	0.31	0.2	0.31	0.34	0.76	0		0.1	0.15	0.18	0.39	0.52	0.3
Averages			#####	#####	#####	#####	#####	0.10	0.41	0.49	0.62	#####	0.15	0.24	0.17	0.14	0.29	0.23	0.50	0.00	#####	0.06	0.04	0.09	0.33	0.48	###

Pressure Bomb Readings

			6/5	6/9	6/16	6/18	6/25	6/27	7/1	7/3	7/8	7/11	7/16	7/18	7/21	7/24	7/29	8/1	8/5	8/8	8/11	8/15	8/19	8/22	8/26	8/29	
1	A	205		15.70			15.70				23.25				18.37	18.15	21.08		16.25	18.00	21.25		13.37			19.75	
1	A	302	12.75	14.70			16.20				23.70				16.75	16.12	19.75		14.62	19.00	25.75		13.37			21.50	
1	A	409		15.30		13.50	14.20	16.00		21.00	21.75				19.50	18.42	19.50		16.12	18.25	22.75		14.50			21.50	
1	B	206		15.30			15.20				23.25				17.66	15.75	19.50		15.12	16.10	20.50		12.87			16.75	
1	B	301	13.55	14.70			15.20				21.00				16.37	15.87	20.42		16.92	18.50	24.75		16.00			25.25	
1	B	408		15.60	12.00	11.00	14.30	15.75		19.50	19.00				15.33	13.50	22.37		14.87	17.50	21.25		13.80			21.50	
1	C	204		14.35			14.00				21.00				16.62	14.92	21.30		15.87	18.25	20.62		16.00			22.00	
1	C	303	12.40	14.80			15.20				21.50				16.17	15.50	21.50		17.50	19.00	22.50		14.08			19.00	
1	C	407		14.80	11.50	11.00	14.50	15.50	19.00	19.00	21.00				16.50	15.50	19.87		14.37	17.50	20.62		14.30				
Averages			12.90	15.03	11.75	11.83	14.94	15.75	19.00	19.83	21.72	#####	#####	#####	17.03	15.97	20.59	#####	15.74	18.01	22.22	#####	14.25	#####	#####	20.91	###
2	A	209					20.20				14.90		20.00	22.75		13.12	19.87	N/A	24.75		14.37		12.37				
2	A	308	13.70				19.30				14.85		20.70	21.75		14.75	17.63	N/A	21.50		14.00		17.37			24.25	
2	A	406				13.75	18.70			14.00	15.30	16.30	19.00	17.67		13.50	17.37	17.25	23.12		16.58		18.00				
2	B	207					19.70				13.50		18.75	19.50		13.12	20.42	N/A	20.90		10.87		14.42			23.25	
2	B	309	12.90				19.30				16.00		17.70	19.25		13.62	17.12	N/A	21.75		14.50		17.50			23.25	
2	B	404			14.50	14.25	18.00		13.00		13.25	16.30	19.25	20.75		13.42	17.87	20.00	22.75		13.87		17.00			20.25	
2	C	208					17.80				14.10		17.40	19.62		13.92	15.75	N/A	19.50		11.75		16.00			21.00	
2	C	307	12.70				19.20				14.30		17.80	19.25		14.12	17.75	N/A	22.00		13.37		16.17			24.00	
2	C	405			14.25	15.50	16.20				14.75	15.75	19.00	19.17		12.62	17.33	17.25	21.58		12.25		14.00				
Averages			13.10	#####	14.38	14.50	18.71	#####	13.00	14.00	14.55	16.12	18.84	19.97	#####	13.58	17.90	18.17	21.98	#####	13.51	#####	15.87	#####	#####	22.67	###
3	A	202									21.30				14.58	13.62	17.13	17.75	21.37		13.00		17.50			21.25	
3	A	304	12.90								22.75				14.50	13.08	18.50	17.75	22.16		13.62		14.62			21.50	
3	A	401							21.00		23.25				13.17	11.50	17.67	18.00	21.75		14.50		17.50			23.00	
3	B	201									20.20				13.25	13.58	18.00	16.50	21.75		12.87		13.00			20.00	
3	B	306	12.50								24.50				13.75	12.50	16.12	17.00	20.75		12.25		15.60			20.50	
3	B	402							21.00		25.00				14.00	12.75	16.62	17.00	22.00		13.25		15.75			22.00	
3	C	203									24.40				15.00	12.00	15.87	15.75	21.50		12.62		14.50			18.00	
3	C	305	12.70								21.75				12.83	13.42	15.87	17.75	20.50		13.00		14.30			19.50	
3	C	403									23.00				14.67	12.25	16.50	20.50	19.00		14.00		14.75			22.00	
Averages			12.70	#####	#####	#####	#####	#####	21.00	#####	22.91	#####	#####	#####	13.97	12.74	16.92	17.56	21.20	#####	13.23	#####	15.28	#####	#####	20.86	###
			5	9	16	18	25	27	1	3	8	11	16	18	21	24	29	1	5	8	11	15	19	22	26	29	31

1=low stress, 2=medium stress, 3=high stress A=SJ-2, B=SJC-1, C=GC510

M.D. M.D. M.D. M.D. Missing M.D. M.D.

1986

COMPARISON OF THE SCHEDULER™ PLANT STRESS MONITOR AND THE PRESSURE CHAMBER FOR COTTON IRRIGATION SCHEDULING

Bronson Gardner, Standard Oil Engineered Materials
in Cooperation with
Lowell J. Zelinski, Farm Advisor
University of California, Cooperative Extension
and Crop Care Associates, Fresno

The Scheduler™ Plant Stress Monitor was compared with leaf water potential readings collected with a pressure chamber device between July 8 and August 29, 1986, on 27 plots of cotton, on which three varieties and three irrigation treatments were imposed. The treatments were:

1) First irrigation at 15 bars
2) First irrigation at 19-20 bars
3) First irrigation at 23 bars

All other irrigations were at 19-20 bars.

Varieties:

1) Acala SJ-2
2) Acala SJC-1
3) Acala GC-510

A Scheduler™ sample encompasses between 3 and 3,000 plants, depending on the way the sensor gun is aimed. As used in this study, each Scheduler™ index was the average of about 10-15 plants. (A minimum of 12 Scheduler™ samples per plot was made). By contrast leaves from only 4 plants per plot were sampled with the pressure chamber.

Data Analysis

Since the primary purpose of Scheduler™ and pressure bomb irrigation scheduling activities is to help growers maximize yields, the data was divided according to yield into three groups:

1) Yields between 2.0 and 2.5 bales/acre
2) Yields between 2.5 and 3.0 bales/acre
3) Yields between 3.0 and 3.5 bales/acre

The minimum and maximum readings of the Scheduler™ index and pressure chamber are given for each date. (Tables 1-3).

Discussion

The greatest range in index and pressure chamber readings occurred in the highest yielding plots (Table 3). In practical terms, this means that plant to plant variability is normal and that a sufficient number of samples must be collected in order to insure that a representative average is obtained. Taking enough data to insure accuracy is a simple process with the Scheduler™ since it can acquire 4 samples per second.

Increasing the number of pressure chamber readings beyond 4 or 5 was not feasible due to the length of time needed per sample. The most accurate interpretation of these results comes by examining the averages (Table 4).

The results show that the highest yields were obtained on the plots which were cool during July and most of August (index readings between 0-3) then became somewhat hotter during late August (index reading of 4-6). This trend was identical for the pressure chamber readings.

This experiment did not examine the stress status of cotton plants during May and June. Perliminary indications from 1987 are that stress index readings of 4-5 are normal in healthy plants during this period.

Conclusions

1. The Scheduler™ and pressure chamber have very similar response patterns between plots which differed in yields (Tables 1-4).

2. Recommended Stress index reading and pressure chamber values change throughout the season, based on crop development.

3. The rapid data gathering capacity of the Scheduler™ gives it a practical advantage over pressure chamber readings. Thousands of plants can be sampled with the Scheduler™ in the time required to measure the pressure potential of a single leaf.

4. The Scheduler™ is a viable tool for observing plant stress in cotton.

5. These results are consistent with four independent USDA studies and one independent University of California study (Figures 1-4).

Table 1. Data for cotton plots with lint yields ranging between 2.0 and 2.5 bales/acre. Fresno, 1986.

Date	Scheduler Index Range (Min.-Max.)		Pressure Chamber Range (Bars) (Min	Max)
July 8	7.1	7.7	21.3	24.4
July 18	2.4	2.5	no data	
July 21	1.4	2.5	14.6	15.0
July 24	0.5	1.5	12.0	13.5
July 29	2.3	2.6	15.9	17.1
August 1	2.4	2.5	15.8	17.8
August 8	-0.8	0.0	no data	
August 15	-0.4	-0.3	no data	
August 19	0.4	1.2	14.5	17.5
August 22	4.5	5.1	18.0	21.2
August 29	4.5	5.1	18.0	21.2

Table 2. Data for cotton plots with lint yields ranging between 2.5 and 3.0 bales/acre. Fresno, 1986.

Date	Scheduler Index Range (Min - Max)		Pressure Chamber Range (Bars) (Min	Max)
July 8	0.3	6.8	14.9	24.5
July 18	2.0	3.8	22.8	22.8
July 21	1.4	3.2	13.0	14.5
July 24	-0.8	2.2	12.2	14.0
July 29	1.2	4.9	15.8	19.9
August 1	1.7	3.4	16.5	20.5
August 5	2.9	7.7	19.0	24.5
August 8	0.0	0.7	no data	
August 15	-0.5	1.5	no data	
August 19	-0.9	2.0	13.0	21.3
August 22	1.4	6.6	no data	
August 29	3.5	8.2	19.5	22.0

Table 3. Data for cotton plots with lint yields ranging between 3.0 and 3.5 bales/acre. Fresno, 1986.

Date	Scheduler Index Range (Min - Max)		Pressure Chamber Range (Bars) (Min	Max)
July 8	-0.4	6.3	13.3	25.0
july 18	-2.2	4.1	17.5	21.8
July 21	0.8	2.6	13.3	19.5
July 24	-2.2	1.6	11.5	19.0
July 29	-0.4	6.5	15.8	22.4
August 1	-0.3	2.6	17.0	20.0
August 5	1.0	7.2	14.4	24.7
August 8	-0.8	3.7	16.1	19.0
August 15	-0.3	0.9	no data	
August 19	-0.7	2.7	12.8	18.0
August 22	1.6	5.2	no data	
August 29	4.3	7.4	16.8	25.3

Note: Statistical analysis of the sampling variation in Scheduler™ and pressure chamber readings show that a minimum of 5400 plants per field should be sampled with the Scheduler™ or 120 pressure chamber readings per field. 5400 plants can be sampled with the Scheduler™ in 2-3 seconds.

Table 4. Average data for Scheduler™ and pressure chamber on plots with three yield ranges. Fresno, 1986.

Date	2.0-2.5 bales/ acre		2.5-3.0 bales/ acre		3.0-3.5 bales/ acre	
	Scheduler	Press. Chamber	Sched- ular	Press. Chamber	Scheduler	Press. Chamber
July 8	7.4	22.9	5.1	19.6	3.3	18.9
July 18	2.5	no data	2.8	22.7	3.3	19.6
July 21	1.9	14.8	1.9	13.8	1.5	16.4
July 24	1.0	12.8	1.2	13.0	-0.7	14.6
July 29	2.5	16.5	3.1	17.4	2.7	15.8
August 1	2.5	16.8	2.4	17.9	1.5	17.0
August 5	5.0	21.5	5.3	21.5	3.8	19.3
August 8	-0.4	no data	0.3	no data	1.0	no data
August 15	-0.3	no data	0.7	no data	0.3	no data
August 19	0.8	16.0	1.0	15.6	0.8	15.4
August 22	2.7	no data	3.8	no data	3.9	no data
August 29	4.8	19.6	5.3	20.7	5.9	21.8

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Figure 1.

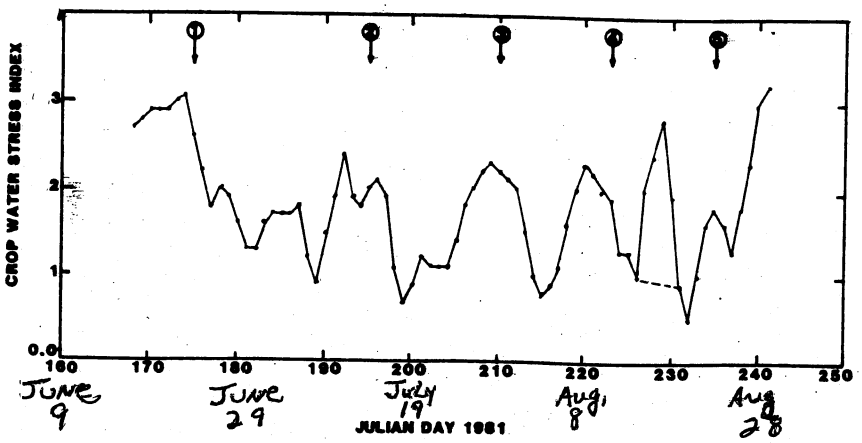


Fig. 5—The 3-day running average of the crop water stress index versus Julian day for cotton growing in California during 1981.

537.6 kg/ha = 1 bale/acre

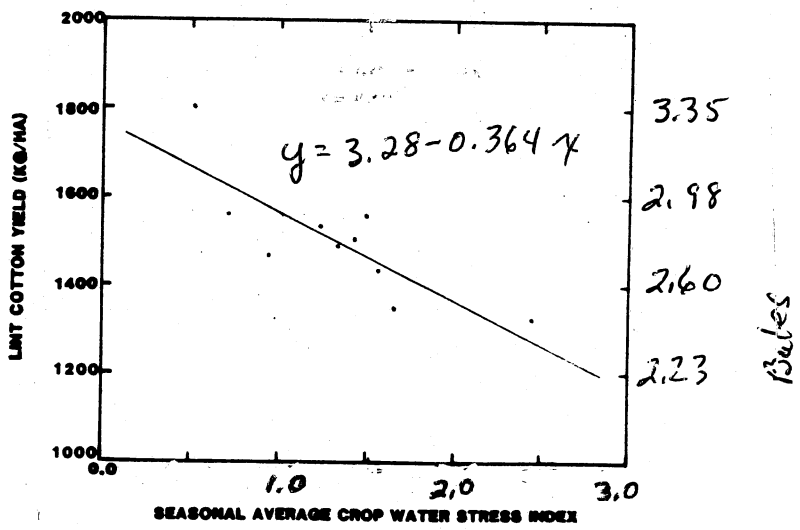


Fig. 6—1981 lint cotton yield from experimental plots in California versus the seasonal average of crop water stress index.

Reginato, R.J. 1983. Field quantification of crop water stress. Transactions of the ASAE 26:772-775,&781.

Location: Phoenix, Arizona

Figure 2.

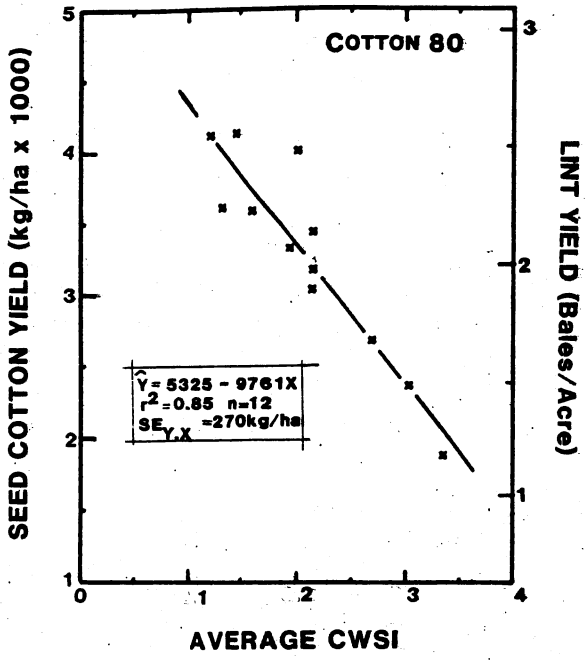


Fig. 4. Cotton yield versus the average daily CWSI measured over the 88-day period from first square until 2 weeks following the last irrigation in August, 1980

Pinter, P.J.,Jr., K.E. Fry, G.Guinn and J.R. Mauney. 1983. Infrared thermometry: a remote sensing technique for predicting yield in water-stressed cotton. Agricultural Water Management 6:385-395.

location : Univ. of Arizona Cotton Research Center, Phoenix, Arizona

Figure 3

$y = 3.99 - 0.496x$

1 bale = 537.6 kg / acre ha

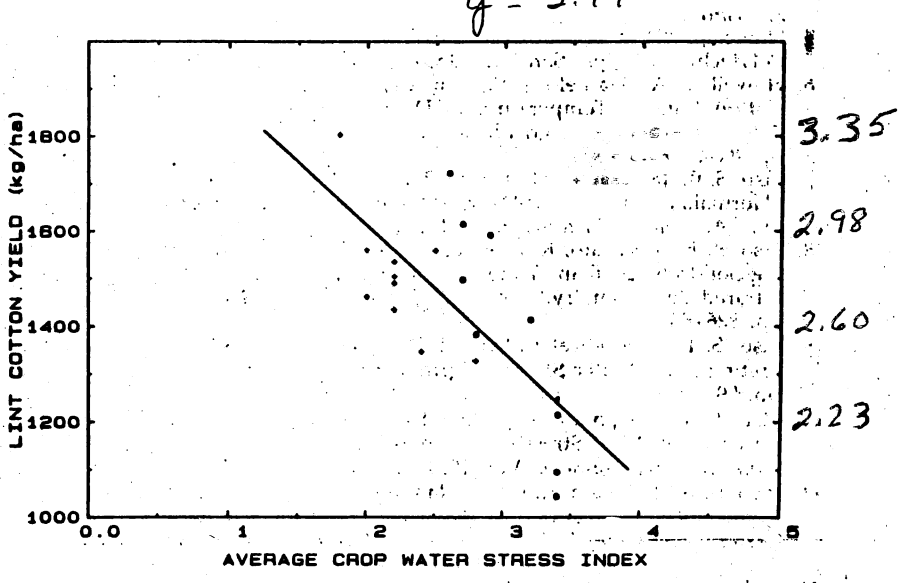
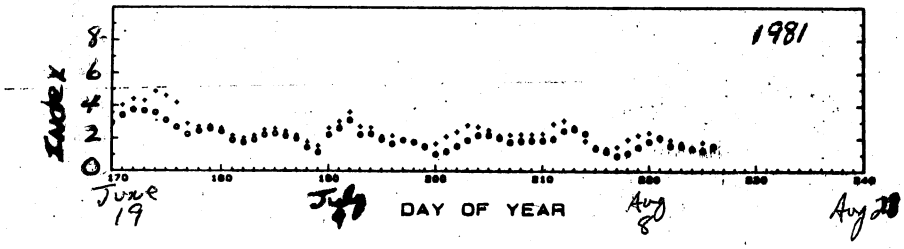
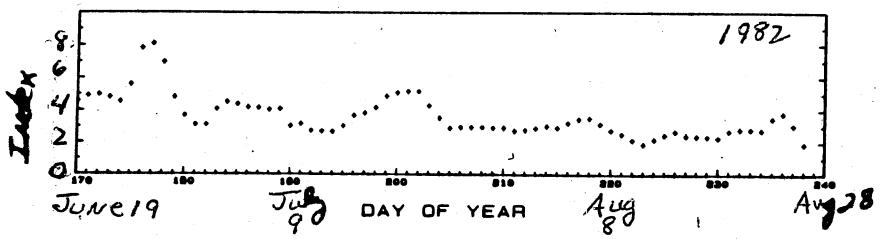


FIG. 5.—Lint Cotton Yield (kg/ha) versus Average Crop Water Stress Index for 1981 and 1982





Sample data for stressed plots in 1981 and 1982.

Reginato, R.J. and J. Howe. Irrigation Scheduling using crop Indicators. 1985. Journal of Irrigation and Drainage Engineering. pg. 125-132.

location : Westlake Farms, Stratford, California

Figure 4

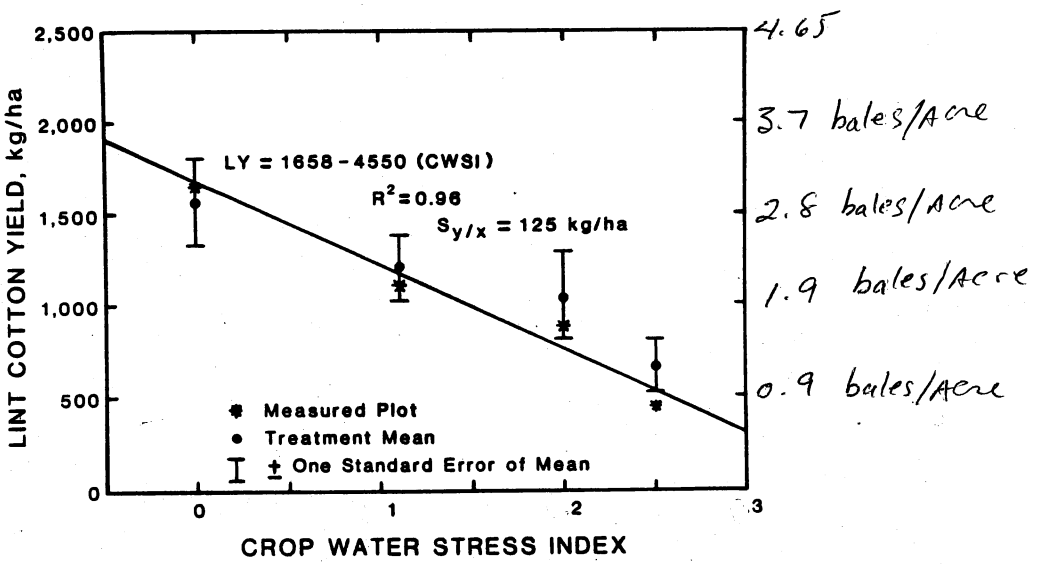


Fig. 7. Relationship between final harvested lint yield and crop water stress index on July 30, 1981

$537.6 \frac{kg}{ha}$ = 1 bale/acre

Howell, T.A., J.L. Hatfield, J.D. Rhoades, and M.Meron. 1984. Response of cotton water stress indicators to soil salinity. Irrigation Science 5:25-36.

Location : Riverwest Farms, Inc, near Lost Hills, Calif.

2 IRRigations

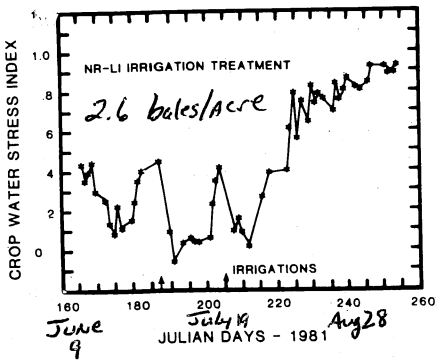


Fig. 5—Seasonal trend in the crop water stress index for NR-LI at the University of California West Side Field Station.

0 IRRigations

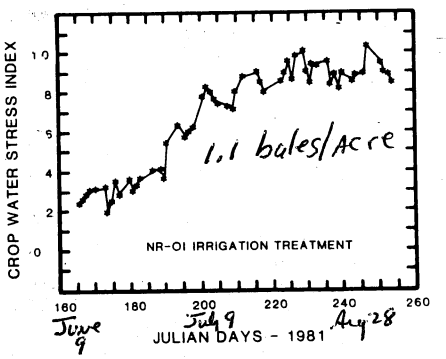


Fig. 6—Sasonal trend in the crop water stress index for NR-OI at the University of California West Side Field Station.

Three IRRigations

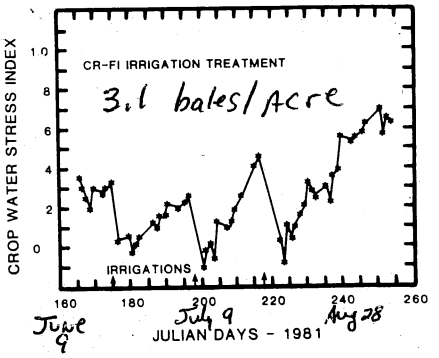


Fig. 7—Seasonal trend in the crop water stress index for CR-FI at the University of California West Side Field Station.

Howell, T.A., J.L. Hatfield, H. Yamada, K.R. Davis. 1984 Evalutation of cotton canopy temperature to detect crop water stress. Transactions of the ASAE 27:84-88

location : West side field stationn near Five Points California and Riverwest Farms, near Lost Hills, Calif

Irrig Sci (1984) 5:25–36

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Response of Cotton Water Stress Indicators to Soil Salinity

T. A. Howell[1], J. L. Hatfield[2], J. D. Rhoades[3], and M. Meron[1]*

[1] USDA-ARS, Fresno, California, USA
[2] Land, Air and Water Resources Department, University of California, Davis, California, USA
[3] USDA-ARS, Riverside, California, USA

Received March 29, 1983

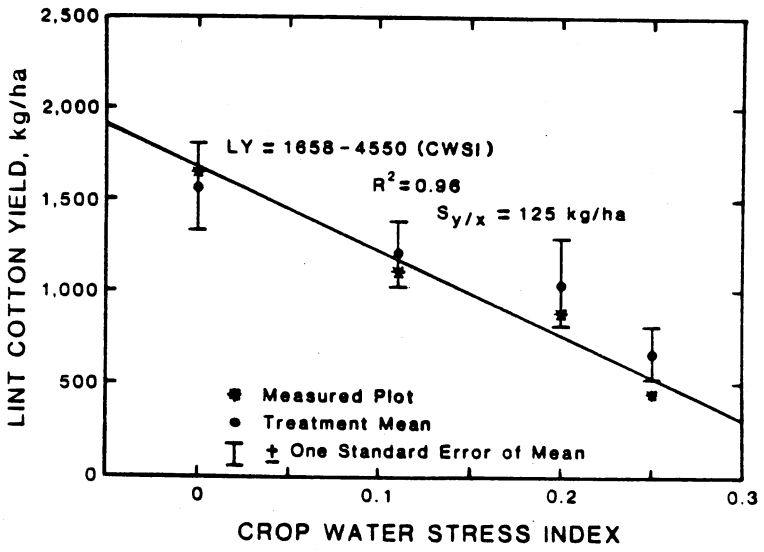

Fig. 7. Relationship between final harvested lint yield and crop water stress index on July 30, 1981

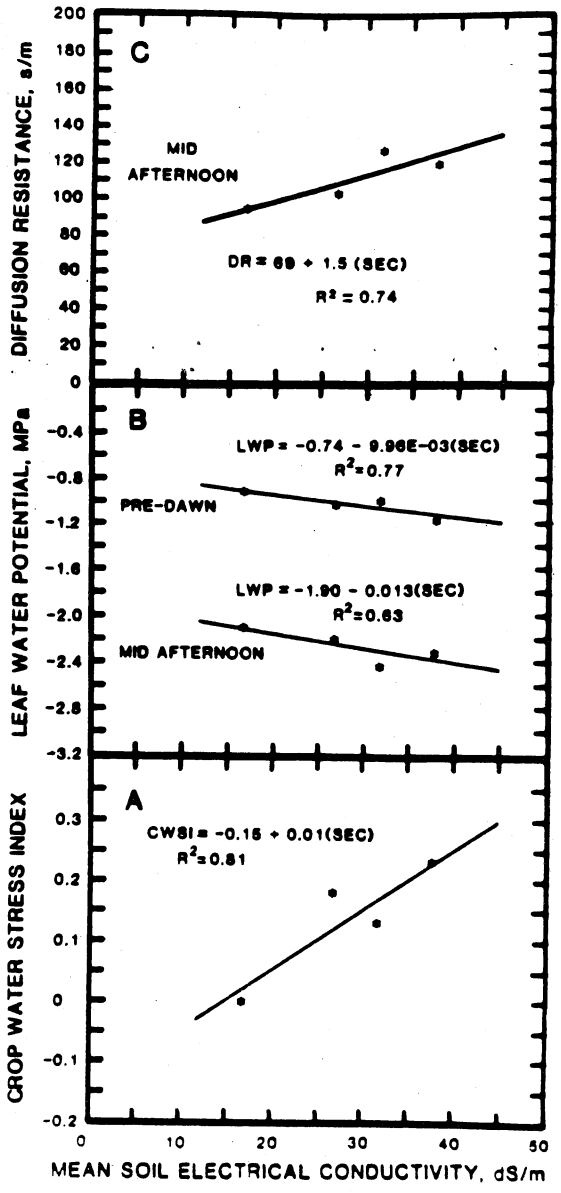

Fig. 4. The relationship between mid-afternoon crop water stress index, pre-dawn and mid-afternoon leaf water potentials and mid-afternoon leaf diffusion resistance and mean rootzone soil water electrical conductivity on July 30, 1981

Evaluation of Cotton Canopy Temperature to Detect Crop Water Stress

T. A. Howell, J. L. Hatfield, H. Yamada, K. R. Davis
MEMBER
ASAE

ABSTRACT

CANOPY temperature of cotton was shown to be useful as an indicator of crop water stress resulting from both soil water deficit (matric) and soil water salinity (osmotic) stresses. The relationship between canopy-air temperature difference and ambient vapor pressure deficit was shown not to depend on cotton row spacing, not to exhibit seasonal trends and to be applicable to a wide cotton production region. Cotton lint yields from two experiments were found to be negatively correlated to the mean seasonal crop water stress index. The crop water stress index was found to be sensitive to crop osmotic stress resulting from high soil water salinity when the soil water matric potential was negligible. Canopy and air temperature difference, in conjunction with ambient vapor pressure measurements, formulated into the crop water stress index appears to be useful in quantifying crop water stress from both soil water deficits and soil salinity. Therefore the crop water stress index appears useful for indicating the need for irrigating cotton.

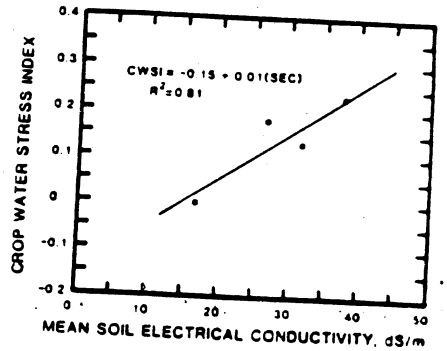

Fig. 11—Relationship between the crop water stress index and mean rootzone soil water electrical conductivity at Riverwest Farms for July 30, 1981.

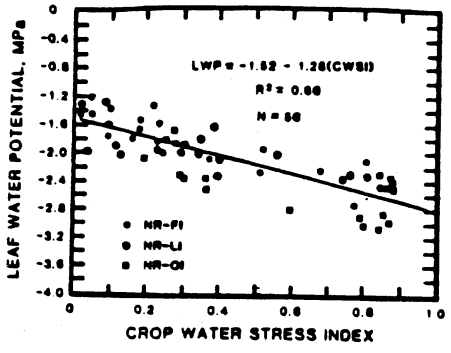

Fig. 8—Relationship between leaf water potential and crop water stress index for narrow row Acala (SJ-2) cotton under limited irrigation at the University of California West Side Field Station.

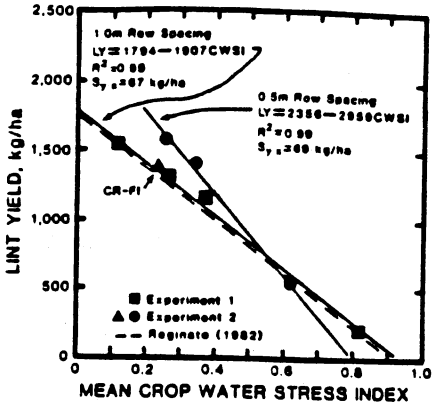

Fig. 9—Relationship between lint cotton yield and seasonal mean crop water stress index for narrow row and conventional row spacings at the University of California West Side Field Station.

Article was submitted for publication in January, 1983; reviewed and approved for publication by the Soil and Water Div. of ASAE in June, 1983. Presented as ASAE Paper No. 82-2532.

Contribution from USDA-ARS, Western Region and the University of California.

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Field Quantification of Crop Water Stress

Robert J. Reginato

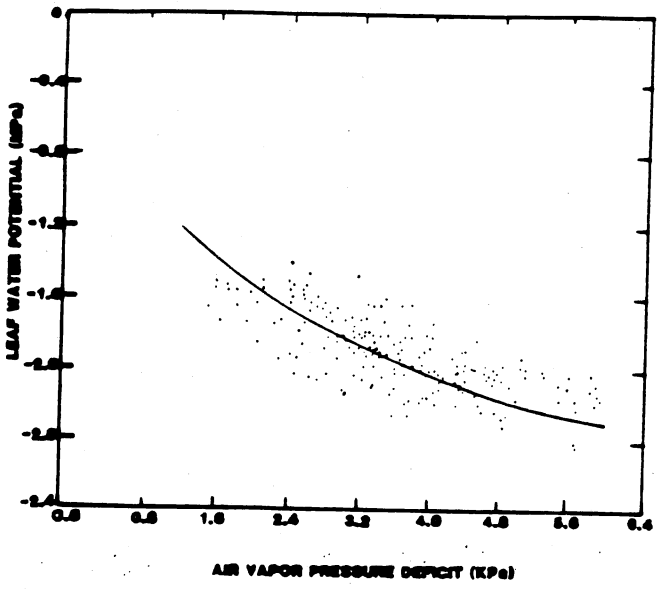

Fig. 2—Total leaf water potential versus air vapor pressure deficit for cotton plants transpiring at the potential rate.

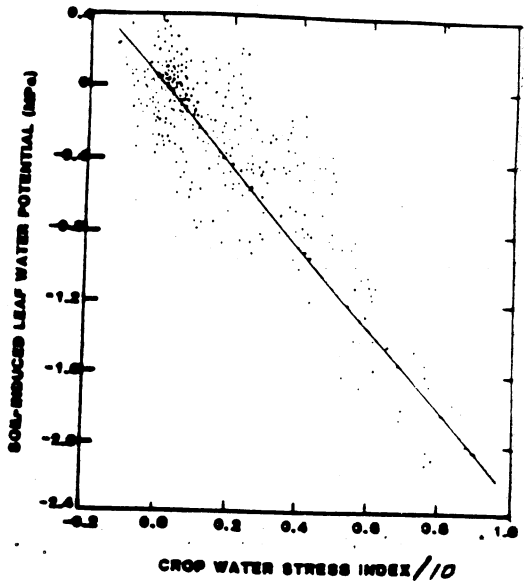

Fig. 3—The soil-induced component of total leaf water potential versus the crop water stress index for cotton.

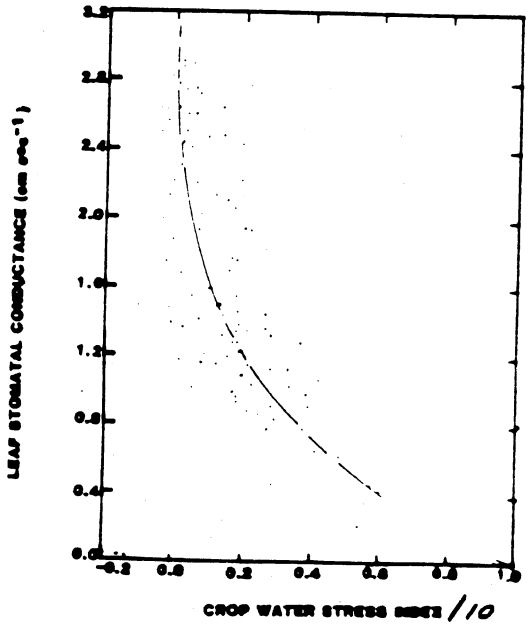

Fig. 4—The stomatal conductance of cotton leaves versus the crop water stress index.

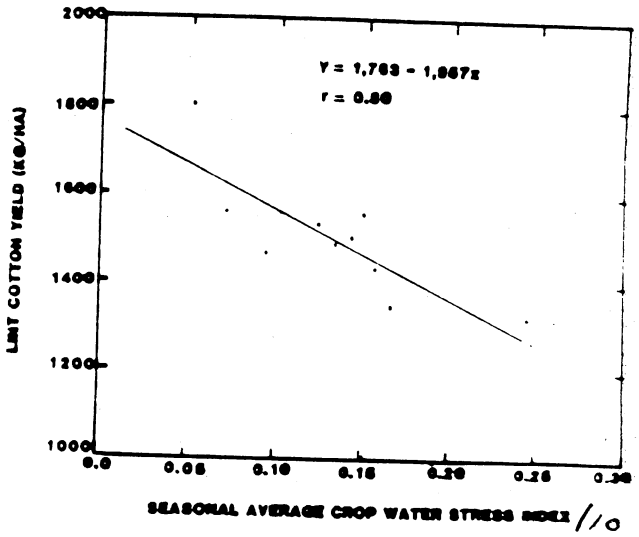

Fig. 6—1981 lint cotton yield from experimental plots in California versus the seasonal average of crop water stress index.

Article was submitted for publication in June, 1982; reviewed and approved for publication by the Soil and Water Division of ASAE in November, 1982. Presented as ASAE Paper No. 82-4007.

The author is: ROBERT J. REGINATO, U.S. Water Conservation Laboratory, USDA-ARS, Phoenix, AZ.

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LEAF WATER POTENTIAL AND THE PLANT STRESS INDEX

The purpose of leaf water potential (LWP) measurements is to provide growers an indirect estimate of how much water is in the soil. The parameter that is being directly measured with LWP is the transpiration rate of the leaf (Rosenberg, et al., 1983):

$$LE = \frac{LWP - Pa}{r_c + r_a} \qquad (1)$$

LWP = leaf water potential
Pa = water potential of the air
r_c = resistance of a crop to transpiration
r_a = aerodynamic resistance to water vapor flow
LE = transpiration rate

The water potential of air is (Rosenberg, et al. 1983):

$$Pa = \frac{RT_a}{V_w} \ln(RH) \qquad (2)$$

R = gas constant
T_a = air temperature
V_w = volume occupied by one mole of water vapor
ln(RH) = natural logarithm of relative humidity

The transpiration rate of a leaf is also equal to (Hatfield et al., 1983):

$$LE = R_n + G - d\,\frac{(T_l - T_a)}{ra} \qquad (3)$$

RN = Net Radiation
G = Soil Heat Flux, a Function of Ground Cover
D = Density of Air * Heat Capacity of Air
Tl = Leaf Temperature
TA = Air Temperature

Substituting equations 2 and 3 into equation 1:

$$(Rn + G) - \frac{d(Tl-Ta)}{ra} = \frac{[LWP - \frac{RTA}{Vw} \ln (RH)]}{rc + ra}$$

Thus,

$$(rc + ra)\,(Rn + G) - \frac{d(rc + ra)\,(Tl - Ta)}{ra} = LWP - \frac{RTA}{Vw} \ln(RH) \qquad (4)$$

Leaf water potential is therefore:

$$LWP = (rc + ra)(Rn + G) - \frac{d(rc + ra)(Tl - Ta)}{ra} + \frac{RTA}{Vw} \ln(RH) \qquad (5)$$

Equation 5 shows that leaf water potential depends on:

- the stress status of the crop (rc)
- the sunlight intensity (Rn)
- air temperature (Ta)
- windspeed (ra)
- relative humidity RH)
- leaf temperature (Tl)
- percent ground cover (G)

In order to accurately use LWP for determining the stress status of leaves the following conditions must be met:

- Measure LWP at consistent solar radiation levels. Sunlight should be measured to insure consistency.
- Leaf temperatures should be the same for each measurement or a correction for varying leaf temperatures should be applied.
- Air temperatures should be the same or a correction for varying air temperatures should be applied.
- correction for relative humidity variation is necessary.
- correction for windspeed.

Many growers use LWP measurements with a degree of satisfaction. Equation 5 shows that they simply may be in an environment which often has similar values of Rn, Ta, Tl and RH from day to day. As long as weather patterns truly are constant from day to day, uncorrected LWP values can be calibrated to indicate stress levels. Since even in places like Fresno, California the weather changes, growers who use uncorrected LWP values can expect significant variability in the meaning of a given LWP value.

Equation 5 shows that LWP is a direct function of all the parameters composing the Scheduler™ stress index:

$$LWP = f(Rn + (Tc - Ta) + VPD) \qquad (6)$$

When leaf water potential measurements are corrected for environmental variability, there is a strong relationship between LWP and Scheduler™ readings (Idso et al., 1981, Reginato, 1983).

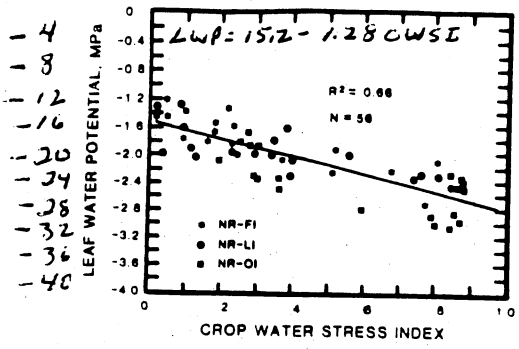
It is clear from a theoretical and empirical viewpoint that LWP values are strongly related to plant stress index readings and that LWP measurements should be corrected for environmental variability before they are compared to Scheduler™ readings.

Hatfield, J.L., A. Perrier and R.D. Jackson. 1983. Estimation of Evapotranspiration at one time of day using remotely sensed surface temperatures. Agricultural Water Management 7:341-350.

Idso, S.B., R.J. Reginato, D.C. Reicosky and J.L. Hatfield. 1981. Determining Soil-Induced Plant Water Potential Depressions in Alfalfa by Means of Infrared Thermometry. Agronomy Journal 73:826-830.

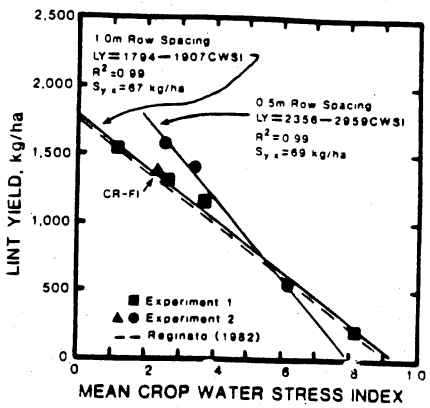
Reginato, R.J. 1983. Field Quantification of Crop Water Stress. Transactions of the ASAE 26:772-775 & 781.

Rosenberg, N.J., B.L. Blad and S.B. Verma. 1983. Microclimate. The Biological Environment. pp. 238-241.



(BARS) −4 −8 −12 −16 −20 −24 −28 −32 −36 −40

Fig. 8—Relationship between leaf water potential and crop water stress index for narrow row Acala (SJ-2) cotton under limited irrigation at the University of California West Side Field Station.



3.72 2.79 1.86 0.93 Bales

Fig. 9—Relationship between lint cotton yield and seasonal mean crop water stress index for narrow row and conventional row spacings at the University of California West Side Field Station.

1 bale = 5 37.6 kg/ha

Howell, T.A., J.L. Hatfield, H. Yamada, K.R. Davis. 1984. Evaluation of cotton canopy temperature to detect crop water stress. Transactions of the ASAE 27: 84-88.

location: West side field station, near Five Points, Calif and Riverwest Farms, near Lost Hills, Calif.

EVALUATION OF THE SCHEDULER™ ON THREE MOISTURE-STRESSED CALIFORNIA COTTON VARITIES

This experiment was conducted in 1986 by the University of California Cooperative Extension Service (Fresno) by Dr. Lowell Zelinski in cooperation with Crop Care Associates (Fresno). Comparisons were made between Scheduler™ stress index readings and conventional pressure bomb readings on ACALA SJ-2, ACALA SJC-1 and ACALA GC-510. The results show that Scheduler™ readings can be used effectively to monitor stress levels in a fraction of the time required to make pressure bomb readings.

TABLE 1:

Average Stress Index	Average Pressure Bomb (P.S.I.)
0	14.9
1	16.0
2	16.9
3	18.6
4	20.2
5	21.4
6	21.9
7	22.0

TABLE 2:

Average Stress Index	Average Bales/Acre Lint
1	3.39
3	3.22
5	2.73

TABLE 3:

Average Stress Index	Average Seed Yield (thousand lbs/acre)
1	5.07
3	4.72
5	4.21

COMPARING SCHEDULER^R READINGS WITH LEAF WATER POTENTIAL MEASUREMENTS

Two experiments have been conducted to determine the relationship between cotton stress index values and leaf water potential measurements. The first study was conducted by the USDA in 1984 at the Westside field station near Five Points, California. They found the following relationship:

$$LWP = 15.2 + 1.28 * \text{Stress Index}, \quad (R^2 = 0.66)$$

In 1986, Lowell Zelinski, University of California Extension in Fresno, found the following:

$$LWP = 14.92 + 1.15 * \text{Stress Index}, \quad (R^2 = 0.61)$$

Although these two equations are virtually identical, this does not mean a user should expect these equations to predict an exact value of LWP for a given Scheduler^R reading. Predictions based on these equations may have a range of $\pm$ 4 bars.

Several factors could cause predictions of LWP measurements based on Scheduler^R readings to differ from measured values by other users.

a. These equations were developed for the most recently fully expanded leaves (usually the third or fourth from the apex). Others may sample different leaves.

b. Variation among users in determining the end-point. Apparently the USDA and University of California researchers had similar end-point techniques. Determination of an end-point is an art (usually consistent for a given user) but can vary greatly between users.

c. Influence of crop growth stage on Scheduler^R readings. The above equations are average trends for a season. These equations probably are not constant throughout a season, but are a function of percent ground cover and age of the crop.

d. Influence of the environment on LWP readings. Theoretical equations have been developed which show that LWP is a function of environmental conditions.

e. Influence of sample size. LWP readings are made on single leaves. Scheduler^R readings encompass a canopy.

#4 B.

RELATIONSHIP BETWEEN CWSI AND CORRECTED PRESSURE BOMB DATA ON 3 ACALA COTTONS
JULY 8,18,21,24,29 AND AUGUST 1,5,8,19,29
FRESNO , CALIFORNIA

16:13 WEDNESDAY, JUNE 3, 1987

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: PRESSURE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	2	1479.48091374	739.74045687	171.48	0.0	0.628173	11.5905
ERROR	203	875.73248432	4.31395312		ROOT MSE		PRESSURE MEAN
CORRECTED TOTAL	205	2355.21339806			2.07700581		17.91990291

SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
VPD	1	384.68741568	89.17	0.0001	1	444.92646331	103.14	0.0001
V27	1	1094.79349806	253.78	0.0001	1	1094.79349806	253.78	0.0001

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > ITI	STD ERROR OF ESTIMATE
INTERCEPT	14.53425685	18.18	.	0.79926077
VPD	1.92433941	10.16	0.0001	0.18948519
~~V27~~ (Tc-Ta)	1.25081728	15.93	0.0001	0.07851732

CPRESS

#5 C.

RELATIONSHIP BETWEEN CWSI AND UNCORRECTED PRESSURE BOMB DATA ON 3 ACALA COTTONS
JULY 8,18,21,24,29 AND AUGUST 1,5,8,19,29
FRESNO , CALIFORNIA

16:13 WEDNESDAY, JUNE 3, 1987

GENERAL LINEAR MODELS PROCEDURE

DEPENDENT VARIABLE: CWSI

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	1	1551.64679827	1551.64679827	12173.27	0.0	0.974308	15.8443
ERROR	321	40.91577247	0.12746347		ROOT MSE		CWSI MEAN
CORRECTED TOTAL	322	1592.56257074			0.35702026		2.25330102

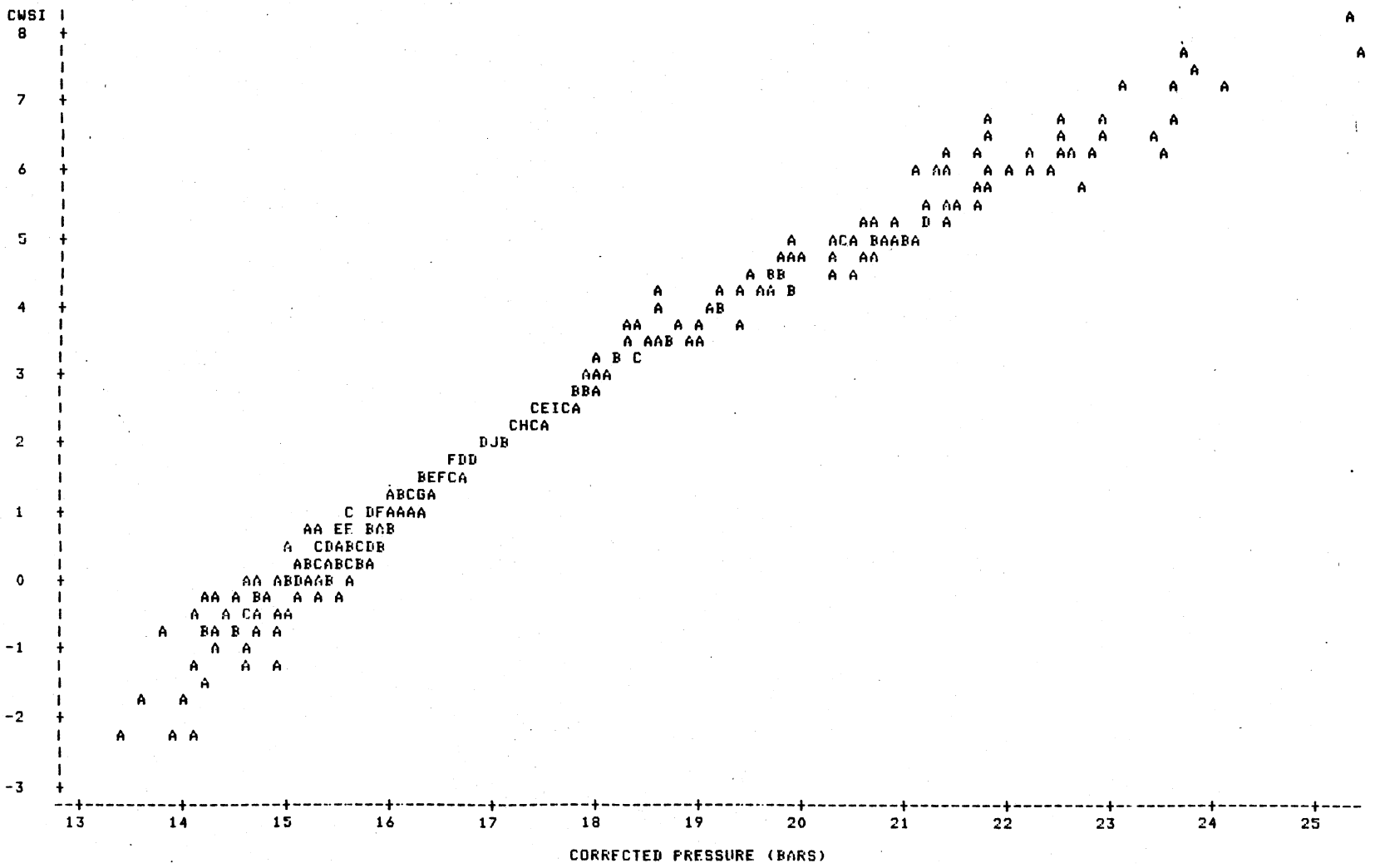
SOURCE	DF	TYPE I SS	F VALUE	PR > F	DF	TYPE III SS	F VALUE	PR > F
CPRESS	1	1551.64679827	12173.27	0.0	1	1551.64679827	12173.27	0.0

PARAMETER	ESTIMATE	T FOR H0: PARAMETER=0	PR > ITI	STD ERROR OF ESTIMATE
INTERCEPT	-12.96538262	-93.04	.	0.13935783
CPRESS	0.86999331	110.33	.	0.00788519

#6 D.

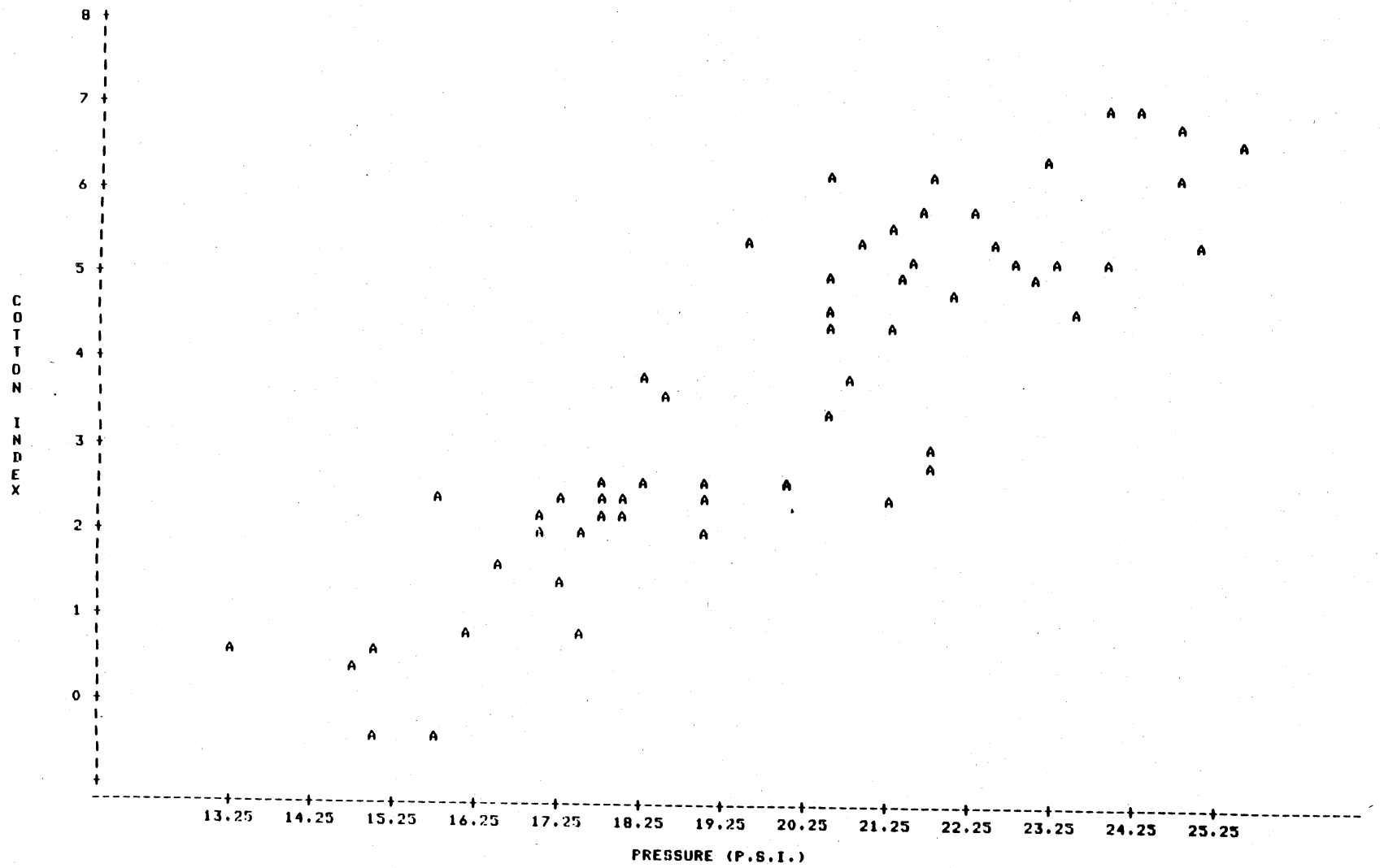
RELATIONSHIP BETWEEN CWSI AND CORRECTED PRESSURE BOMB DATA ON 3 ACALA COTTONS 5
JULY 8,18,21,24,29 AND AUGUST 1,5,8,19,29 16:13 WEDNESDAY, JUNE 3, 1987
FRESNO , CALIFORNIA

PLOT OF CWSI*CPRESS LEGEND: A = 1 OBS, B = 2 OBS, ETC.



RELATIONSHIP BETWEEN CWSI AND PRESSURE BOMB
COTTON (5 DATES BETWEEN JULY 8 AND AUGUST 12, 1986)
FRESNO , CALIFORNIA

PLOT OF CWSI*PRESSURE LEGEND: A = 1 OBS, B = 2 OBS, ETC.



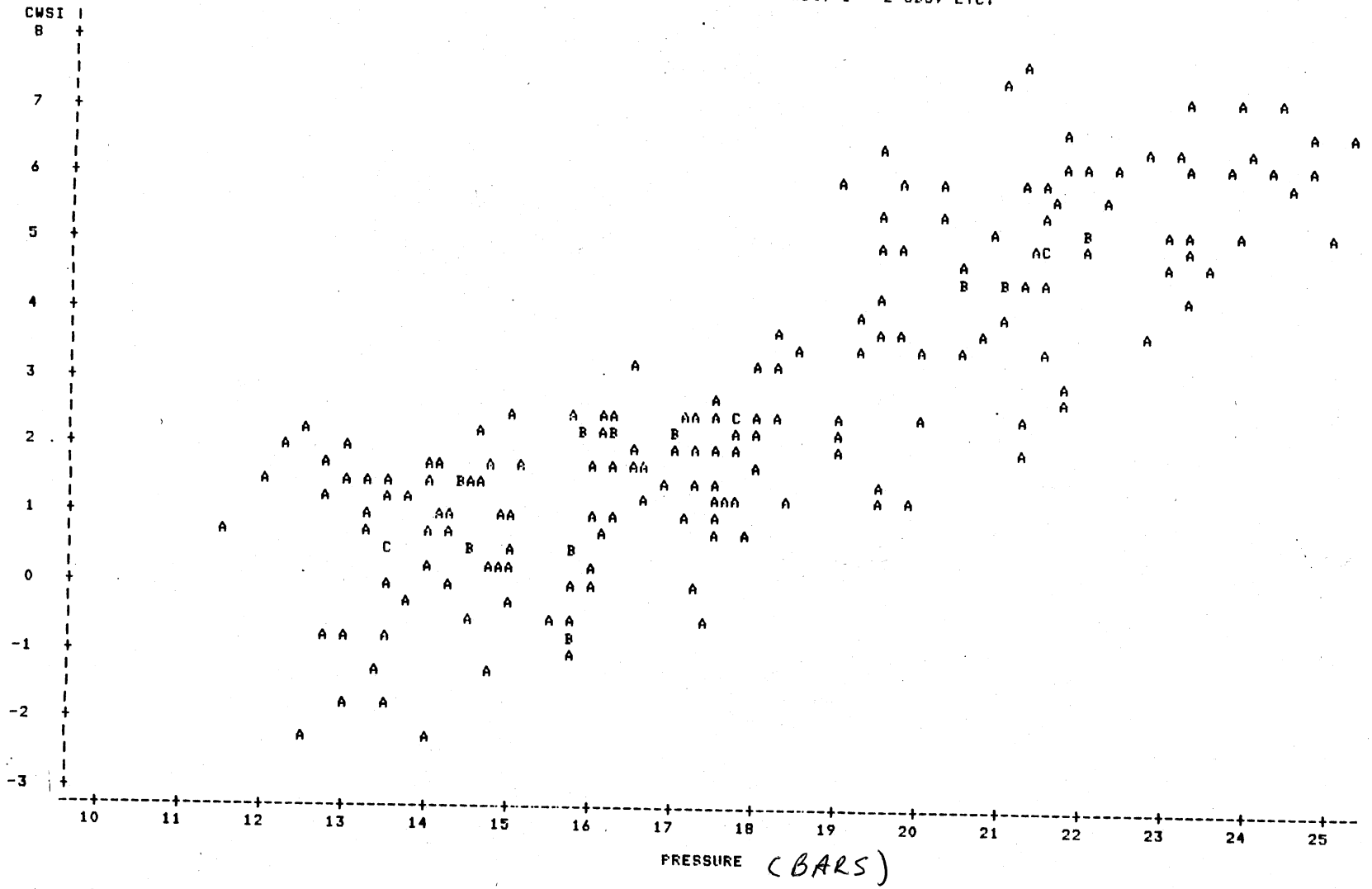
#4

RELATIONSHIP BETWEEN CWSI AND UNCORRECTED PRESSURE BOMB DATA ON 3 ACALA COTTONS
JULY 8,18,21,24,29 AND AUGUST 1,5,8,19,29
FRESNO , CALIFORNIA

16:13 WEDNESDAY, JUNE 3, 1987

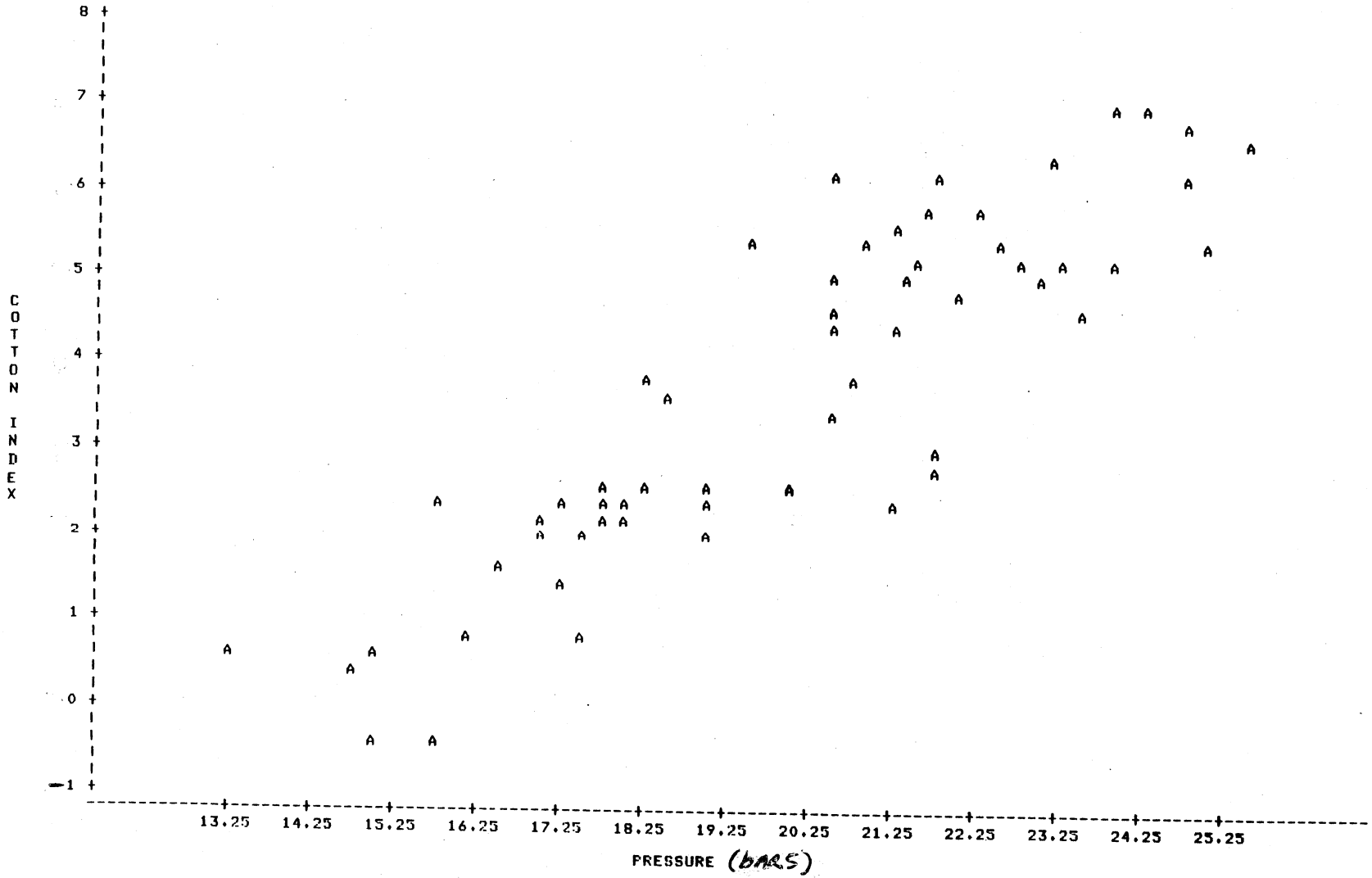
A.

PLOT OF CWSI*PRESSURE LEGEND: A = 1 OBS, B = 2 OBS, ETC.



RELATIONSHIP BETWEEN CWSI AND PRESSURE BOMB
COTTON (5 DATES BETWEEN JULY 8 AND AUGUST 12, 1986)
FRESNO , CALIFORNIA

PLOT OF CWSI*PRESSURE LEGEND: A = 1 OBS, B = 2 OBS, ETC.



Comparison of the Infrared Thermometer and the Pressure Chamber for Cotton Irrigation Scheduling

Lowell J. Zelinski
Farm Advisor
University of California
Cooperative Extension
Fresno

December 1986

Introduction

In cooperation with Crop Care Associates, an evaluation of Standard Oil of Ohio's infrared thermometer, (IRT) (the Scheduler) for irrigation scheduling in cotton was made. The IRT is linked to a microprocessor which converts leaf temperature readings to stress index values. The stress index values were collected approximately two times per week, and they were compared to leaf water potential readings collected with a pressure chamber device.

A cotton field which was used as an irrigation scheduling experiment was chosen for monitoring. The field was planted on April 15, 1986 to either Acala SJ-2, Acala SJC-1 or Acala GC-510. Three irrigation regimes which involved timing of the first irrigation was imposed on each of the three varieties. A summary of the treatments is below.

Irrigation Treatments:

1) First Irrigation at 15 bars
2) First Irrigation at 19-20 bars
3) First Irrigation at 23-23 bars.

Varieties:

1) Acala SJ-2
2) Acala SJC-1
3) Acala GC-510

Irrigation for all treatments following the first one were at leaf water potential readings of 19 to 20 bars.

Results

A table is included which includes all of the available information on pressure bomb readings and IRT readings for each of the dates and treatments sampled. Also included are three charts which compare IRT readings and pressure bomb readings for each of the three irrigation treatments over time. The values graphed are the average of the three varieties and of the replications where the measurements were taken.

Discussion

Early in the season IRT readings were more erratic then later in the season. This can be attributed to learning to use the IRT and because the plants were small at times significant amounts of soil surface was picked up by the IRT. Later in the season this variability decreased.

The IRT readings on July 24th in the all the treatments seem incorrect. The precise reason is not clear, but one possibility is the weather on the two days prior to the 24th. The table below summarizes the weather.

Date	Max	Min	Rainfall (in)
7/22	92	69	0
7/23	82	65	.04
7/24	90	62	0

The amount of rain on the 23rd, although small, may have had some effect on the readings obtained on the 24th.

For the most part the IRT readings seemed to follow the pressure bomb readings well. Using linear least squares regression the following relationships were developed:

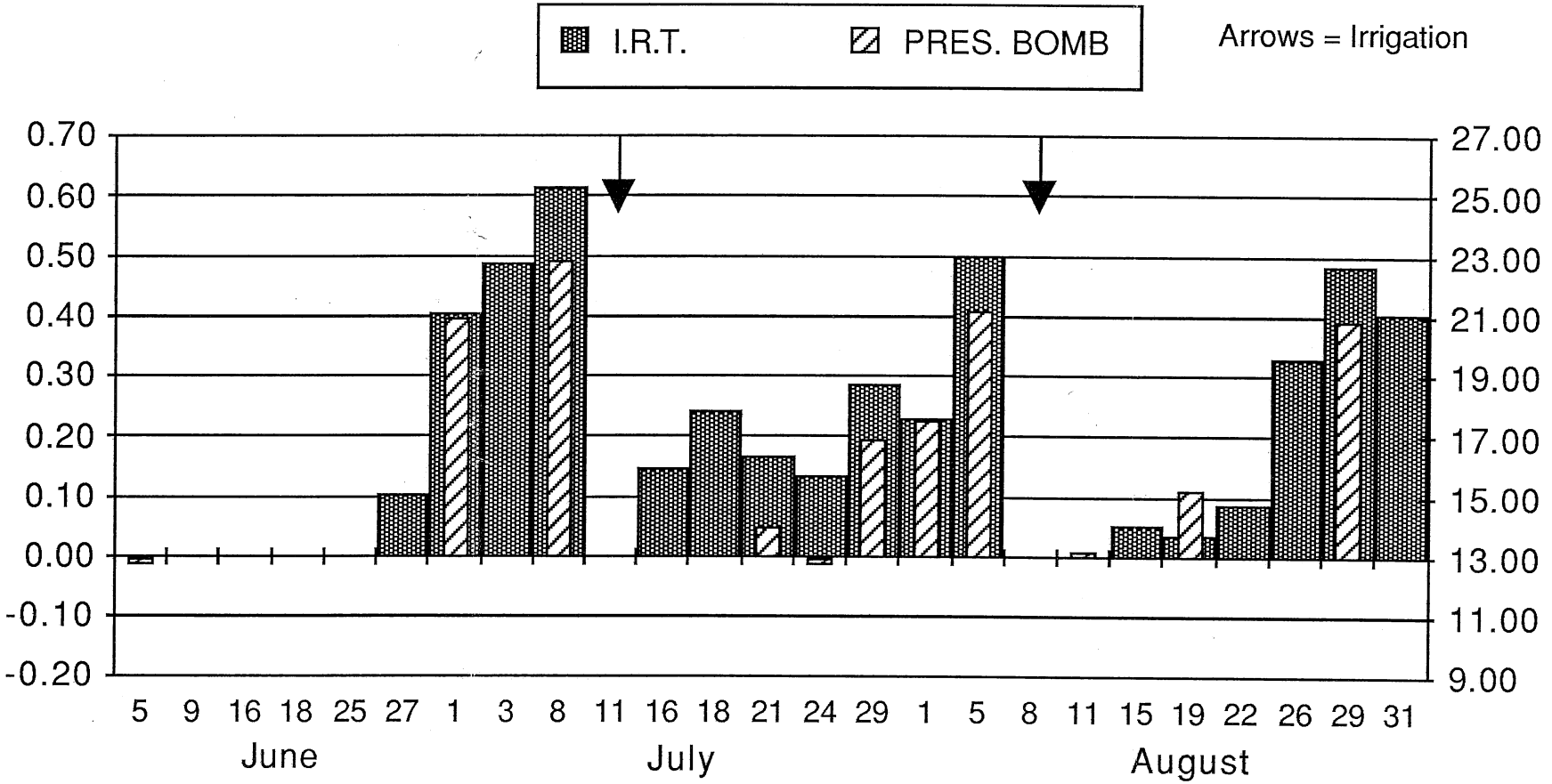
	IRT = -.65 + .05(PB)	r^2 = .60	(1)
or	PB = 14.7 + 11.7(IRT)	r^2 = .60	(2)

for the entire season of data. The r^2 values are highly significant, but in analysis of this information I have some problems. The following table illustrates my concerns.

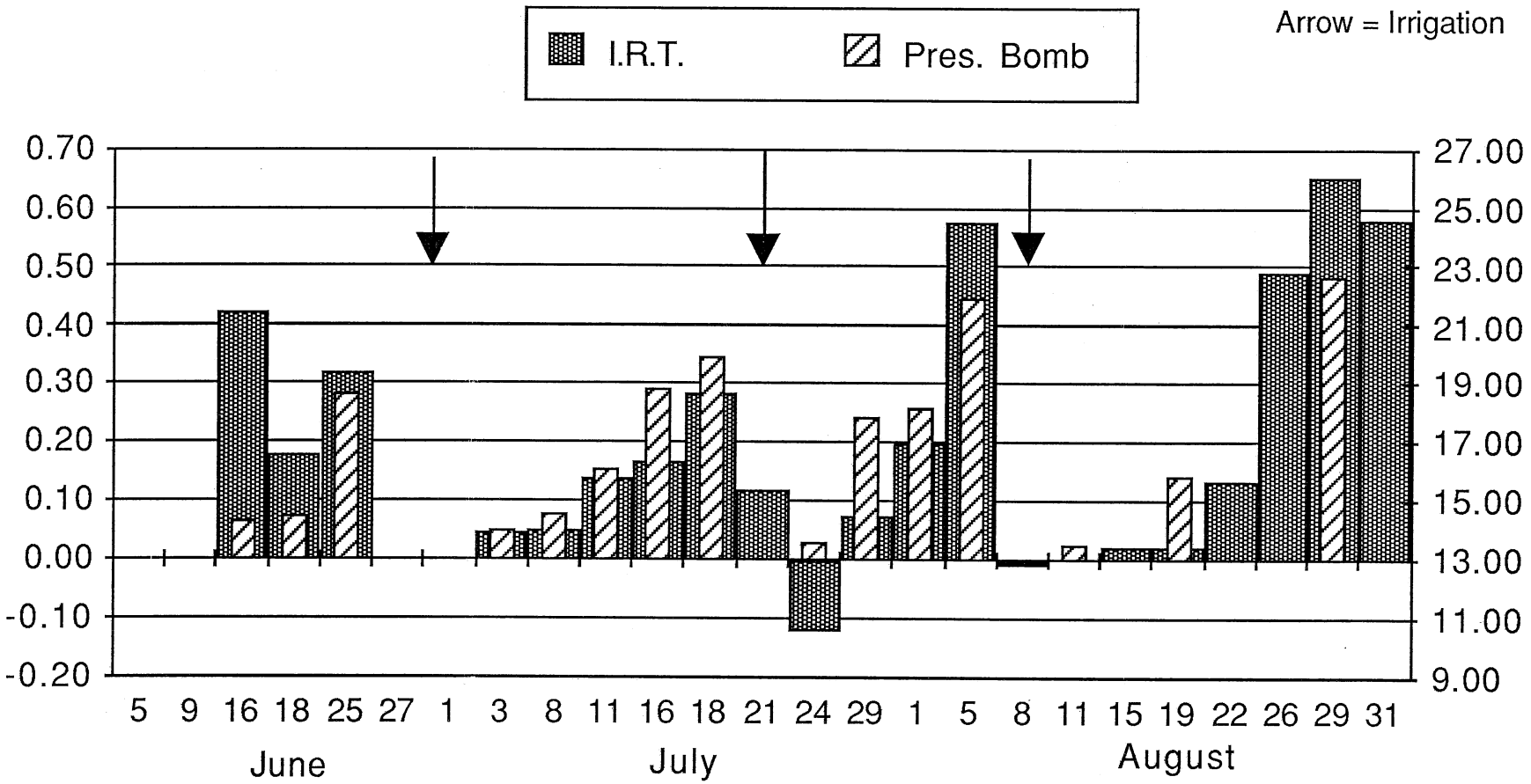
EQUATION 1 PB	IRT	Irrigation Decision Based on PB	EQAUTION 2 PB	IRT	Irrigation Decision Based on PB
17	.20	Maybe	.20	17.0	maybe
19	.30	YES	.30	18.2	optimum
21	.40	late	.40	19.4	ok
23	.50	very late	.50	20.6	slightly late

Depending on which equation is used, different interpretation of IRT stress index values can be obtained. I am currently not sure how to reconcile this dichotomy. Though I feel the IRT has promise as an irrigation scheduling tool in cotton, but the stress index values which should be used to recommend an irrigation are not clear.

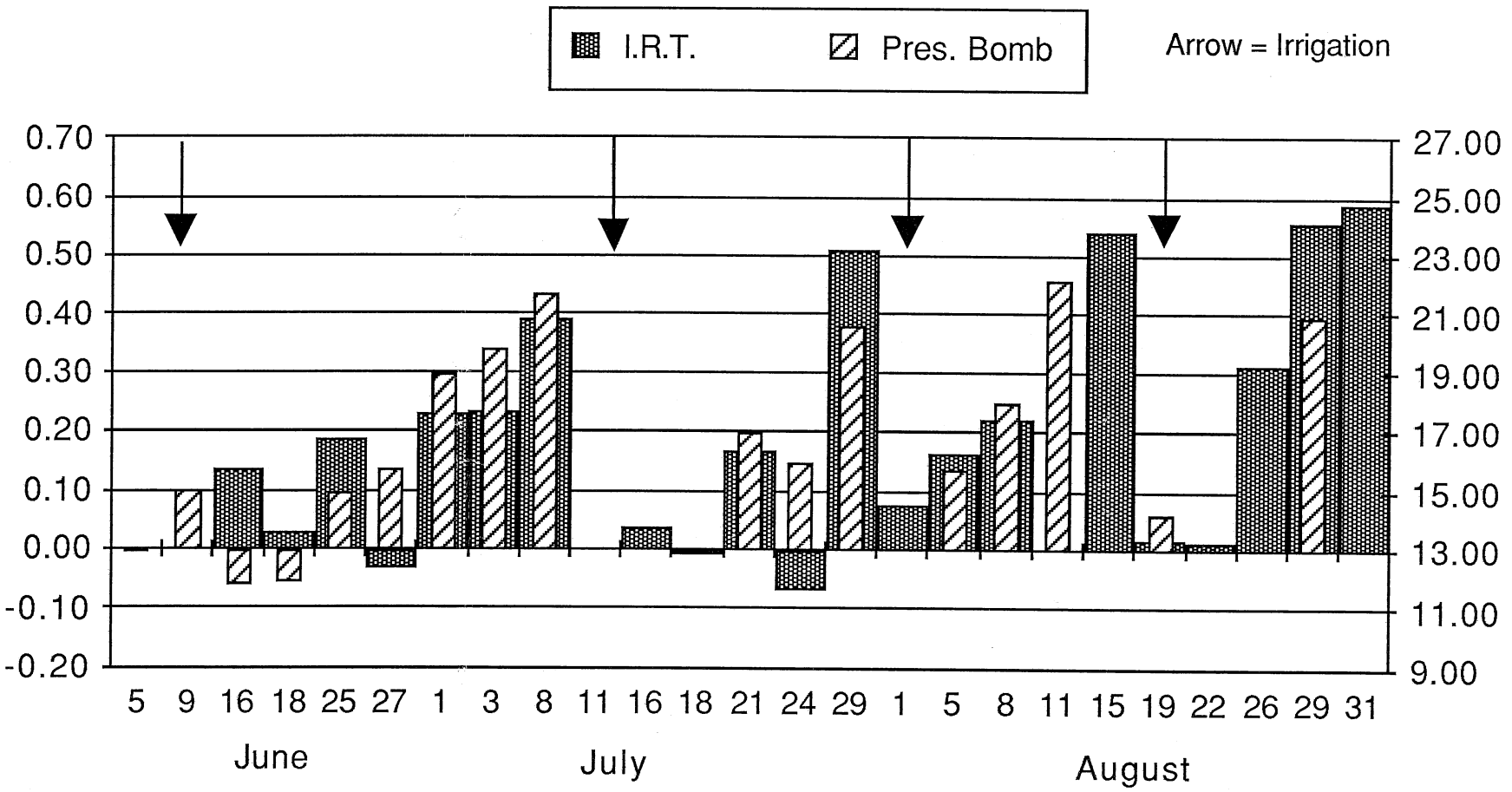
I.R.T. & PRESSURE BOMB COMPARISON
HIGH STRESS TREATMENT



I.R.T. & Pressure Bomb Comparison
Medium Stress Treatment



I.R.T. & Pressure Bomb Comparison
Low Stress Treatment



Crop Care Services Inc.
APPLIED AGRICULTURAL TECHNOLOGY

January 7, 1987

Bronson Gardner, Ph.D.
SOHIO Engineered Materials Company
4440 Warrensville Center Road
Cleveland, Ohio 44128

Dear Bronson:

I am enclosing the Lint Yield information from the irrigation trial of this past summer. On the last page, I have calculated the lint yields for each treatment and variety.

I hope this will be of some use.

Sincerely,

Jim Hill

JH:wh
Enclosure

1557 W. Shaw Avenue • Fresno, CA 93711 • 209/221-1476

	A	B	C	D	E	F	G
1	1986 CWEM 1		WSFS				
2							
3							
4				MAIN PLOT	SUB PLOT		
5				1=15 BAR	1=SJ-2	1ST PICK	2ND PICK
6	PLOT	REP	TREAT	2=19 BAR	2=SJC-1	SEED COT.	SEED COT.
7	NO.	NO.	NO.	3=23 BAR	3=GC-510	LBS/PLOT	LBS.PLOT
8							
9							
10	101	1	1	2	3	186	4.9
11	102	1	2	2	2	186	5.8
12	103	1	3	2	1	208	5.4
13	104	1	4	1	1	214	5.2
14	105	1	5	1	3	191	6.0
15	106	1	6	1	2	195	6.0
16	107	1	7	3	1	156	5.4
17	108	1	8	3	2	147	5.8
18	109	1	9	3	3	147	8.5
19	201	2	8	3	2	155	9.1
20	202	2	7	3	1	149	8.2
21	203	2	9	3	3	141	8.6
22	204	2	5	1	3	186	4.4
23	205	2	4	1	1	204	5.4
24	206	2	6	1	2	205	7.0
25	207	2	2	2	2	183	6.4
26	208	2	1	2	3	186	6.4
27	209	2	3	2	1	183	4.3
28	301	3	6	1	2	189	4.8
29	302	3	4	1	1	215	4.8
30	303	3	5	1	3	196	4.2
31	304	3	7	3	1	165	17.5
32	305	3	9	3	3	149	8.8
33	306	3	8	3	2	160	15.7
34	307	3	1	2	3	173	5.1
35	308	3	3	2	1	206	5.4
36	309	3	2	2	2	199	8.3
37	401	4	7	3	1	202	11.3
38	402	4	8	3	2	188	11.5
39	403	4	9	3	3	163	7.0
40	404	4	2	2	2	186	6.6
41	405	4	1	2	3	188	7.2
42	406	4	3	2	1	199	5.1
43	407	4	5	1	3	200	6.5
44	408	4	6	1	2	220	7.1
45	409	4	4	1	1	225	6.6

	O	P	Q	R

Lint yields

	GIN TURNOUT	LINT YIELD 1ST PK (LBS/AC)	LINT YIELD 2ND PK (LBS/AC)	TOTAL LINT YIELD (LBS/AC)	Plot
100	.35	1582.18	41.68	1623.86	101
15	.34	1531.57	47.76	1579.32	102
1	.32	1617.67	42.00	1659.66	103
	.32	1658.47	40.30	1698.77	104
3	.35	1618.99	50.86	1669.85	105
2	.33	1558.45	47.95	1606.40	106
1	.31	1171.20	40.54	1211.74	107
8	.35	1246.03	49.16	1295.20	108
9	.34	1210.43	69.99	1280.42	109
3	.33	1238.77	72.73	1311.49	201
7	.32	1154.73	63.55	1218.28	202
1	.34	1161.03	70.81	1231.84	203
3	.35	1576.61	37.30	1613.91	204
1	.34	1679.78	44.46	1724.25	205
2	.32	1588.72	54.25	1642.97	206
5	.35	1551.18	54.25	1605.43	207
6	.35	1576.61	54.25	1630.86	208
1	.33	1462.54	34.37	1496.91	209
2	.34	1550.81	39.39	1590.19	301
1	.33	1712.26	38.23	1750.49	302
3	.35	1655.55	35.48	1691.02	303
7	.32	1274.24	135.15	1409.39	304
9	.34	1222.59	72.21	1294.80	305
8	.34	1312.85	128.82	1441.68	306
0	.36	1503.02	44.31	1547.33	307
1	.32	1590.87	41.70	1632.57	308
5	.34	1627.15	67.87	1695.02	309
7	.32	1559.98	87.27	1647.24	401
8	.34	1542.60	94.36	1636.96	402
9	.34	1337.47	57.44	1394.91	403
5	.34	1526.19	54.16	1580.35	404
6	.35	1587.97	60.82	1648.79	405
4	.32	1536.81	39.39	1576.20	406
3	.35	1689.33	54.90	1744.24	407
2	.33	1745.95	56.35	1802.30	408
1	.32	1737.60	50.97	1788.57	409

		lbs/ac	Bales/ac.
15 bar 0.10 S.I.	SJ-2	1740.52	3.48
	SJC-1	1660.46	3.32
	GC-510	1679.75	3.36
19 bar 0.30 S.I.	SJ-2	1591.34	3.18
	SJC-1	1615.03	3.23
	GC-510	1612.71	3.23
23 bar 0.50 S.I.	SJ-2	1371.66	2.74
	SJC-1	1421.33	2.84
	GC-510	1300.49	2.60

	H	I	J	K	L	M	N
1							
2							
3							
4							
5	TOTAL			TOTAL	6 LB		
6	SEED COT.	ROW	ACRE	SEED COT.	SAMPLE	LINT	SEED
7	WT.-LBS	LENGTH	FACTOR	PER ACRE	WEIGHT	%	%
8				LBS	(grams)		
9							
10	190.9	283	.0411457	4639.61	2861	.38	.62
11	191.8	284	.0412911	4645.07	2835	.38	.62
12	213.4	283	.0411457	5186.45	2686	.36	.64
13	219.2	284	.0412911	5308.65	2760	.37	.63
14	197.0	284	.0412911	4771.01	2638	.39	.61
15	201.0	284	.0412911	4867.88	2733	.38	.62
16	161.4	284	.0412911	3908.84	2796	.36	.64
17	152.8	284	.0412911	3700.56	2634	.39	.61
18	155.5	284	.0412911	3765.95	2578	.38	.62
19	164.1	284	.0412911	3974.22	2834	.38	.62
20	157.2	284	.0412911	3807.12	2658	.36	.64
21	149.6	284	.0412911	3623.06	2873	.38	.62
22	190.4	284	.0412911	4611.17	2674	.39	.61
23	209.4	284	.0412911	5071.31	2617	.38	.62
24	212.0	284	.0412911	5134.28	2845	.37	.63
25	189.4	284	.0412911	4586.95	2740	.38	.62
26	192.4	284	.0412911	4659.60	2799	.39	.61
27	187.3	284	.0412911	4536.09	2951	.37	.63
28	193.8	285	.0414365	4677.04	2833	.38	.62
29	219.8	285	.0414365	5304.51	2810	.38	.62
30	200.2	285	.0414365	4831.49	2839	.39	.61
31	182.5	285	.0414365	4404.33	2935	.37	.63
32	157.8	285	.0414365	3808.24	2813	.39	.61
33	175.7	285	.0414365	4240.23	2818	.38	.62
34	178.1	285	.0414365	4298.15	3027	.40	.60
35	211.4	285	.0414365	5101.79	2640	.37	.63
36	207.3	286	.0415819	4985.35	2790	.38	.62
37	213.3	285	.0414365	5147.64	2886	.37	.63
38	199.5	285	.0414365	4814.60	2797	.39	.61
39	170.0	285	.0414365	4102.67	2820	.39	.61
40	192.6	285	.0414365	4648.08	2866	.38	.62
41	195.2	285	.0414365	4710.83	2685	.39	.61
42	204.1	285	.0414365	4925.61	2599	.37	.63
43	206.5	285	.0414365	4983.53	2551	.39	.61
44	227.1	286	.0415819	5461.52	2792	.38	.62
45	231.6	285	.0414365	5589.28	2838	.36	.64

Cotton

A College of Agriculture Report

Don Garrot

Forbes 437A

SERIES P-69
MARCH 1987

Cooperative Extension Service | Agricultural Experiment Station

The University of Arizona
U.S. Department of Agriculture

Scheduling Irrigations on Cotton Based on the Crop Water Stress Index

Donald J. Garrot, Jr., Delmar D. Fangmeier and Stephen H. Husman

ABSTRACT

The Crop Water Stress Index (CWSI) was used to schedule irrigations on drip irrigated cotton research plots in Tucson and on eight acre furrow irrigated fields at the Marana and Maricopa Agricultural Centers. Scheduling irrigations when plots reached 0.30 CWSI units resulted in highest yields with 1403 lbs/acre cotton lint using 33.8 inches of water. The Marana and Maricopa fields yielded 1322 lb/acre on 28 inches and 1767 lb/acre on 58 inches of water, respectively.

INTRODUCTION

Typical irrigation scheduling techniques have relied on indirect methods to determine when a crop needs to be irrigated. These methods included soil moisture measurements, estimated evapotranspiration, crop color, crop growth patterns, and fixed schedules. Direct indications of plant water stress have required difficult measurements of leaf water potential, leaf transpiration rates or stomatal resistance.

Recently the U.S. Water Conservation Laboratory in Phoenix developed a promising technique using infrared thermometry. The technique, termed the Crop Water Stress Index (CWSI), uses infrared measurements of crop canopy temperature and the absolute air moisture content (vapor pressure deficit) above the crop. A well-watered nonstressed crop has a CWSI value near zero, while a nontranspiring water stressed crop's CWSI value is near one.

When plots of cotton (DPL 61) in a 1985 drip irrigation test at Maricopa (where plots were irrigated 130% (wet), 100% (medium), and 60% (dry) of Erie's consumptive use value of 41.2 inches every other day) were monitored using the Crop Water Stress Index (CWSI) as an indicator of plant water stress, a highly linear correlation (r=0.997) between the seasonally averaged CWSI and the cotton lint yield by treatment was measured.

A CWSI average value of 0.15 units (wet) correlated to the highest yield of 1545 lb/ac of cotton lint. Higher CWSI average values resulted in lower lint yields where a maximum CWSI average value of 0.26 units for the dry treatment yielded 843 lb/ac of cotton lint.

The linear correlation between seasonally averaged CWSI and lint yields indicated a straight line relationship. However, when the data were plotted, a leveling effect in yield could be observed when CWSI values were lower than 0.15 units.

A similar linear relationship (r=0.991) was also measured in 1985 at Marana on a 10 acre field planted with two different cotton cultivars (DPL 90 and DPL 41). They were scheduled for irrigation with the CWSI and irrigated using a linear move equipped with furrow drop lines and overhead boom-mounted sprayers.

The lowest seasonally averaged CWSI value measured was 0.09 units yielding 1648 lb/ac of cotton lint, and the highest seasonally averaged CWSI value was measured at 0.22 units yielding 1166 lb/ac cotton lint.

To determine if yields leveled off, increased, or decreased at seasonally averaged CWSI values of less than 0.15 units, a drip irrigation test was designed where plots would be scheduled for irrigation using the

Crop Water Stress Index at 0.0 units (wet), 0.15 units (medium), and 0.30 units (dry). Results should indicate the CWSI value at which irrigations should be scheduled to obtain maximum cotton lint yields.

In addition, eight acre bulk cotton fields at Marana and Maricopa were scheduled for irrigation when their CWSI values neared 0.15 units.

MATERIALS AND METHODS

Plots of cotton (Deltapine 90) were planted May 5, 1986 in Tucson at the Campus Agricultural Center of the University of Arizona. Three water treatments were established based on irrigation scheduling using the crop water stress index. Four replicated plots were irrigated when their CWSI measurements reached or exceeded 0.0 (wet), 0.15 (medium), and 0.30 (dry) units. Plots were irrigated utilizing buried trickle tubing for precision water delivery.

Neutron soil moisture measurements were used to determine the soil moisture deficiency in each plot at each irrigation. The corresponding volume of water was metered onto each plot using volumetric shutoff valves. The CWSI and soil moisture measurements were taken on each plot on the average of three times weekly when skies were clear.

Bulk fields planted April 15 and 17 at the Marana and Maricopa Agricultural Centers were furrow irrigated laser leveled fields having a slight slope (about 0.015%). To obtain high irrigation efficiencies, both fields were irrigated using high furrow flow rates for short periods of time.

At Marana, about 45 gpm/furrow was delivered for 70-90 minutes, which applied about three inches of water over the 600 foot run. At Maricopa, about 90 gpm/furrow was delivered for about 75 minutes, which applied about four inches of water over the 800 foot run. Moisture measurements were taken before each irrigation, while CWSI measurements from the four corners of each field were collected three times weekly.

Four 50-foot rows of each plot were harvested by machine in Tucson on November 6, 1986. The Marana field was picked on October 15 and November 24, 1986 and the Maricopa field was picked on December 4 and 29, 1986.

RESULTS AND DISCUSSION

The effect of CWSI irrigation scheduling on lint yield, total water applied, and number of irrigations scheduled, including the preplant, over the three locations are listed in Table 1. The dry treatment, which had a CWSI at irrigation of 0.30 and a seasonally averaged CWSI of 0.17, had significantly higher lint yields with the lowest water applied and fewest number of irrigations. This correlates well with previous results, which indicated highest yields should be attained at a seasonally averaged CWSI near 0.15 units. Lower seasonally averaged CWSI values did significantly decrease yields and required more applied water and total number of scheduled irrigations. This shows that some crop stress increases lint yields.

Table 1. Effect of CWSI irrigation scheduling on cotton lint yields, total water applied, and number of irrigations at three locations.

Location	TRT	Av. CWSI at Irrigation*	Seasonally Av. CWSI*	Lint Yield* (lb/ac)	Total Water* (in)	# of Irr.
Tucson	Wet	0.10 b	0.06 b	1178 c	48.5 a	22
	Med	0.21 ab	0.10 ab	1290 b	37.4 b	12
	Dry	0.30 a	0.17 a	1403 a	33.8 b	8
Marana	-	0.18	0.09	1322	28.0	10
Maricopa	-	0.21	0.11	1767	58.0	12

**Numbers followed by the same letter are not significantly different at the (.05) level using Waller Duncan K-Ratio T-Test.*

The results indicate that if CWSI irrigation scheduling were to be used on large acreages, fields should be scheduled for irrigation when the CWSI value nears 0.30 units. This value was obtained from same-day trickle irrigations. Since at the grower level there is usually a 2-4 day delay in obtaining water, irrigations should be scheduled below 0.30 units depending on the length of the delay. Cotton begins to show visible wilt at about 0.35 units.

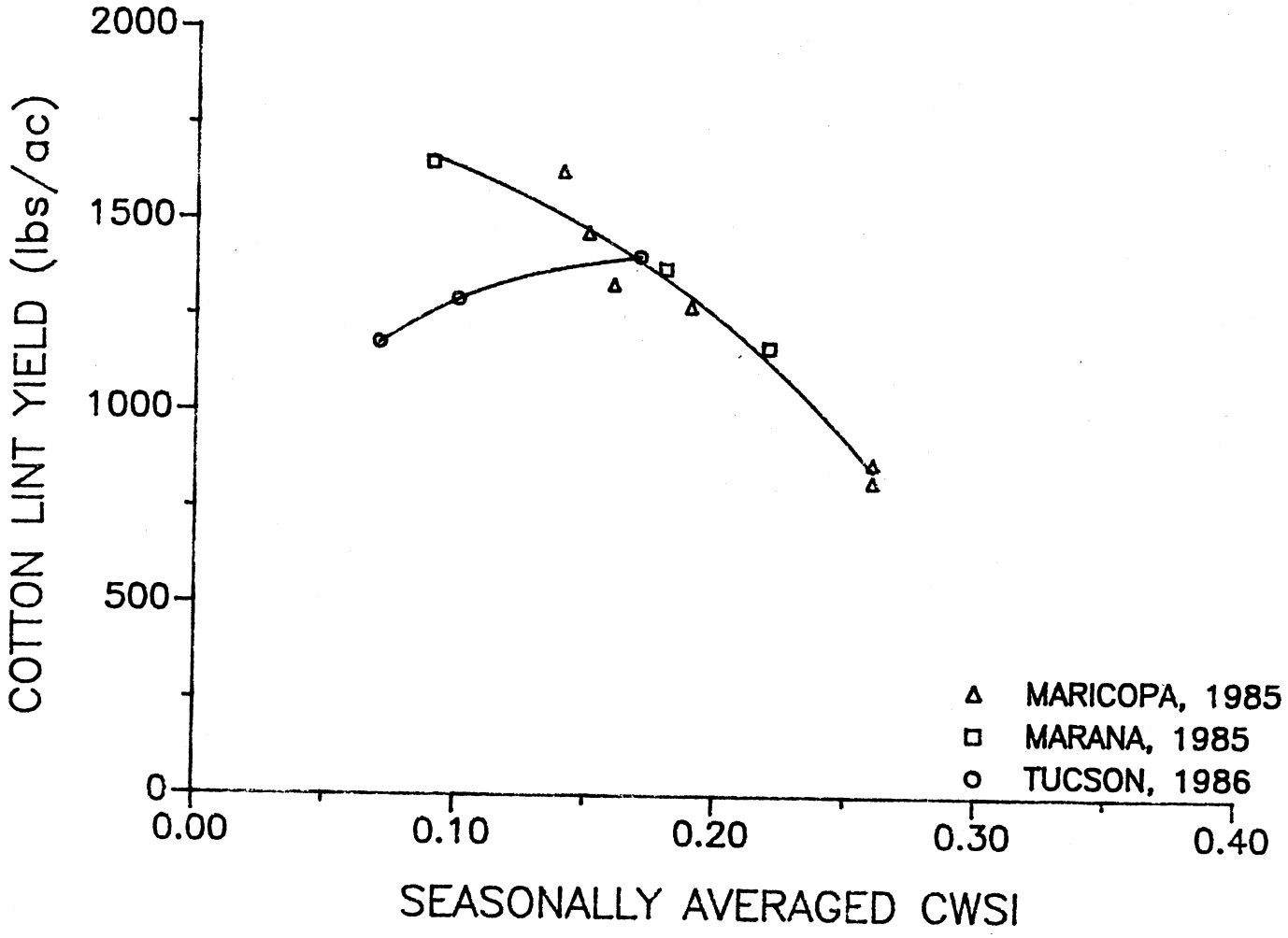
The Marana and Maricopa fields, which were scheduled for irrigation at 0.15 units, actually had average CWSI at irrigation values of 0.18 and 0.21, respectively. These values are very near the same values as the medium treatment in Tucson which resulted in a significant reduction in yield of about 10% from the dry treatment, probably due to overwatering. Although the Marana and Maricopa lint yields of 1322 and 1767 lb/ac are about 450 lbs above county averages, higher yields using less water may be attainable if fields are scheduled at 0.30 units.

Figure 1 is a graphic representation of the relationship of seasonally averaged CWSI and cotton lint yield from the 1985 Maricopa and Marana tests and the 1986 Tucson test. There is a good correlation between the seasonally averaged CWSI and lint yields for both locations and years (Tucson 1986 r=0.97, Maricopa and Marana 1985 r=0.96).

The Tucson 1986 slope is +2137, while the Maricopa and Marana 1985 slope is -5044. The slopes of the two lines indicate that cotton lint yield decreases over twice as rapidly at CWSI values above 0.15 units (underwatered) than at lower CWSI values (overwatered). The results suggest that if optimal irrigation timing can't be met, it is more beneficial yield-wise to over-irrigate DPL 90 rather than to underirrigate.

All three tests will be repeated in 1987.

THE RELATIONSHIP BETWEEN COTTON LINT YIELDS
AND SEASONALLY AVERAGE CWSI
FROM 3 LOCATIONS



United States Department of Agriculture
Agricultural Research Service
Pacific West Area
U.S. Cotton Research Station
17053 Shafter Avenue
Shafter, Ca 93263

August 1, 1988

Bronson Gardner
P.O. Box 391316
Solon, Ohio 44139

Dear Mr. Gardner:

Here are the slopes and intercepts for the alfalfa we have gotten over the past 3 years.

Date	Slope	Intercept	VPD	
			min.	max.
6/09/86	-2.563	2.04	1.56	3.63
5/05/87	-3.457	3.96	1.37	2.21
5/29/87	-4.627	4.47	0.61	2.02
6/23/87	-3.586	4.68	1.40	2.99
7/22/87	-4.212	4.92	1.55	2.49
6/01/88	-3.692	3.93	1.28	2.84

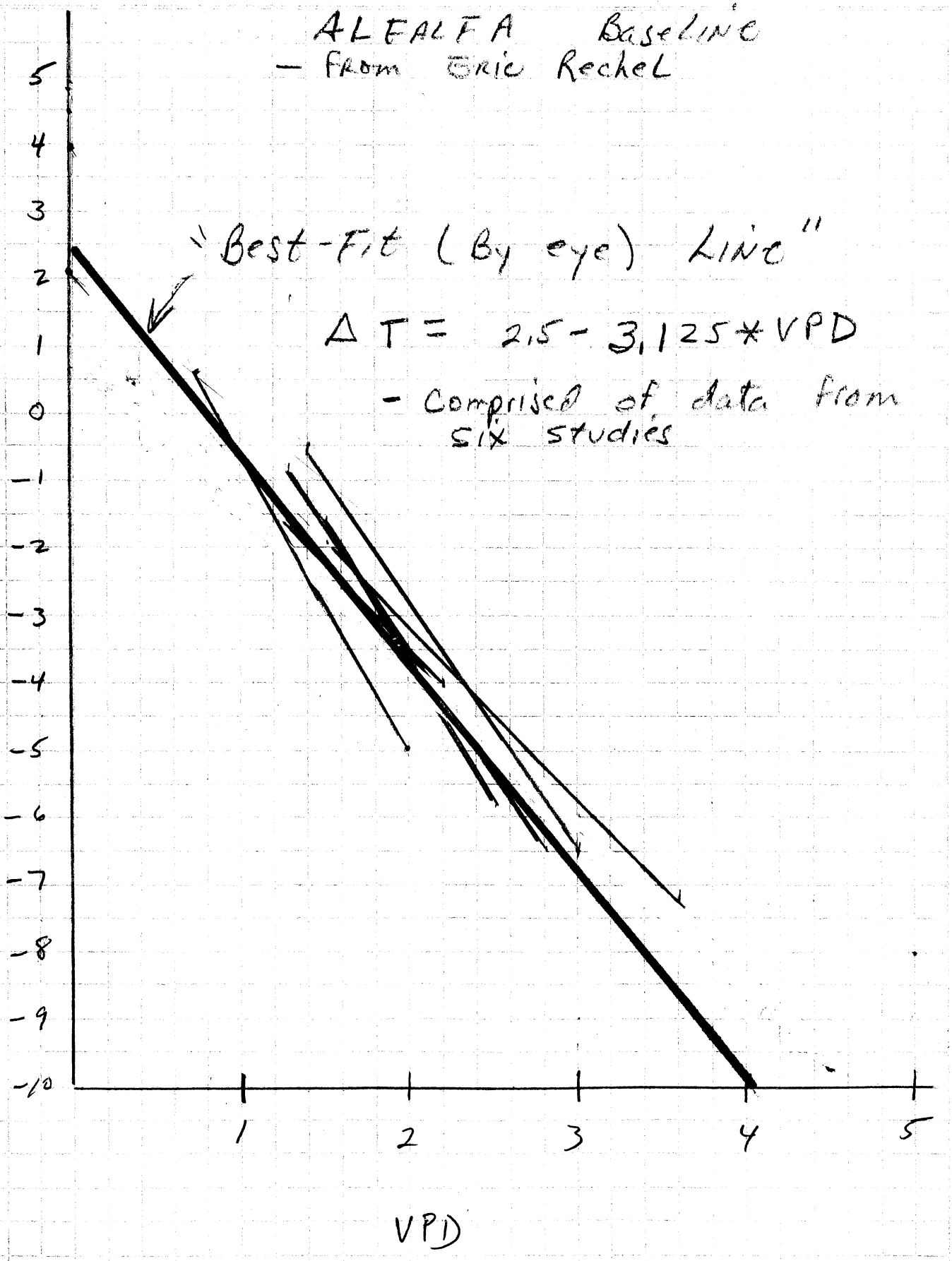
If you need more information let me know.

Sincerely,

Eric A. Rechel

Eric A. Rechel

CLV-193-C


ALFALFA Baseline
- From Eric Rechel
"Best-Fit (By eye) Line"
ΔT = 2.5 - 3.125 * VPD
- Comprised of data from six studies
5
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Pacific West Area

U.S. Cotton Research Station
17053 Shafter Avenue
Shafter, Ca 93263

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Date

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3.63
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2.02
2.99
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Bronson Gardner
P.O. Box 391316
Solon, Ohio 44139

OFFICIAL BUSINESS

United States Department of Agriculture
Agricultural Research Service

USDA, ARS, PWA
U.S. COTTON RESEARCH STATION
17053 SHAFTER AVENUE
SHAFTER, CA 93263

20

SCHEDULER^{TM} FIELD EXPERIMENT -1988

WEST SIDE FIELD STATION
cooperator : Stephanie Johnson
report by : Bronson Gardner

During the 1988 growing season, cotton was monitored with a Scheduler^{tm} plant stress monitor during 3 distinct time periods : June 27-July 13 (period 1), July 20-July 25 (period 2) and on August 17 and August 24 (period 3). This experiment was not designed to evaluate the Scheduler^{tm}, but was instead designed to evaluate the effectiveness of PIX in controlling plant growth and enhancing the yield performance of 3 cotton varieties (GC-510, SJ-2 , and GC-356) and in determing interactions with various irrigation treatments. The PIX treatments were :

1 = control
2 = 1/2 pint pix at first bloom
3 = 1/8 pint pix at match-head square, 1/4 pint at first bloom
4 = 1/4 pint pix at match-head square, 1/2 pint at first bloom

The irrigation treatments applied were in accordance with research conducted in previous years using pressure chamber measurements of leaf water potential. The treatments were

1 = 15 bars at first irrigation
16 bars at all other irrigations

2 = 15 bars at first irrigation
18 bars at all other irrigations

3 = 18 bars at all irrigations

This made a total of 36 separate treatments. With only four replications per treatment, there were a total of 144 plots.

The sheer size of this experiment made the planning of where (and when) to make Scheduler^{tm} readings difficult. Limited staff made it necessary to make a limited number of readings on each plot. The measurement frequency break-down was :

Table 1. Summary of observation frequencies.

total number of readings made on a plot during the 1988 growing season.	number of plots with this sample frequency
0	2
6	14
7	52
8	42
9	17
10	7
11	7
19	2
78	1

Table 1 shows that a large number of Scheduler^{tm} readings were made on a large number of plots, but that few plots were measured very often. This makes it impossible to analyze the Scheduler^{tm} readings using the preferred technique of trend analysis. Insufficient data was taken (on a per plot basis) for any trends to be observed.

A further break-down of the readings shows that Scheduler data was collected on only 14 different days between June 8 and August 24 (a period of 77 days or eleven weeks). On seven of these days, insufficient data was taken to be useful for any comparison between treatments. Thus, only 7 days of data were taken that contain statistically useful information.

Generally, we would expect to have a minimum of 30-40 days of readings during the growing season. Growers can use the Scheduler^{tm} for irrigation scheduling purposes with a lower frequency than this, but experience shows that many important trends will be lost (to a researcher) if the frequency is any less than this. (Table 2)

Table 2. Summary of the number of observations made per day with the Scheduler^{tm} during 1988. A maximum of 144 observations per day was possible.

DATE	DAY OF YEAR	NUMBER OF SCHEDULER READINGS MADE PER DAY	
JUNE 8	159	* 12	
JUNE 20	171	* 12	
JUNE 27	178	* 15	
JUNE 29	180	96	
JULY 1	182	143	16 DAY PERIOD
JULY 8	189	* 12	
JULY 9	190	100	
JULY 11	192	* 36	
JULY 13	194	288	
JULY 20	201	144	
JULY 22	203	* 36	5 DAY PERIOD
JULY 25	206	144	
AUGUST 17	229	109	
AUGUST 24	236	* 53	

* insufficient number of readings to conduct a meaningful statistical test (a few observations were split between too many different treatments and varieties).

Inspection of table 2 shows that valid statistical tests of differences between treatments can be made on data collected on seven different days : June 29, July 1, July 9, July 13, July 20, July 25, and August 17.

RESULTS AND DISCUSSION

Yield analysis

The analysis criteria most cotton growers are interested in is lint yield. The first step in the analysis was to rank the 144 plots according to lint yield. Groups of plots with similar yields were assigned the same ranking number (Appendix I). The rankings were :

Table 3 Number of plots in a given yield range or ranking.

Rank	Lint yield range (lbs/acre)	Number of plots in this yield range
1	< 1100	2
2	1100-1199	12
3	1200-1299	16
4	1300-1399	15
5	1400-1499	24
6	1500-1599	35
7	1600-1699	24
8	1700-1799	12
9	1800-1899	3
10	> 1900	1

The results of this classification allows us to examine the effect of the various treatments applied to the cotton. Table 4 shows that the highest yields (rank 7 or above) tended to occur in variety 2 (SJ-2). Irrigation treatments 1 and 2 appear to have similar effects, but treatment 2 (15 bars at first irrigation and 18 bars for all other irrigations) produced the highest yields (see ranks 8-10). The pix treatments did not have a discernable effect on yields. Table 4 was sub-divided into a low yield group (yield ranks 1-5) and a high yield group (ranks 6-10). The high and low yield groups contain a similar number of observations from each variety. This grouping is the most meaningful one to use in analyzing this Scheduler^{tm} data set.

Table 4. Number of plots in a given yield ranking, according to irrigation treatment, variety, and pix treatment level.

YIELD RANKING	IRRIGATION TRT			VARIETY CODE			PIX TRT			
	1	2	3	1	2	3	1	2	3	4
				LOW YIELD GROUP						
1	0	0	2	0	0	2	0	2	0	0
2	1	0	11	6	1	4	4	2	3	3
3	2	0	14	6	3	7	7	2	4	3
4	1	2	12	3	8	4	4	4	4	3
5	11	6	7	7	9	8	6	6	3	8
TOTAL PLOTS	14	8	19	22	21	25	21	16	14	17
				HIGH YIELD GROUP						
6	21	12	2	15	5	15	11	10	8	6
7	12	12	0	6	10	8	8	5	5	4
8	2	10	0	3	8	1	5	3	1	3
9	0	2	0	0	2	0	2	0	0	1
10	0	1	0	0	1	0	0	1	0	0
TOTAL PLOTS	33	37	2	24	26	24	26	19	14	14

Analysis of Scheduler^{tm} Data

All Scheduler observations were classified as having been taken in either a LOW yielding area (lint yield was less than 1500 lbs/acre) or a HIGH yielding area (lint yield was greater than 1500 lbs per acre). As previously mentioned, grouping the data this way allows for a similar number of observations in each group, with each variety , irrigation treatment, and pix treatment adequately represented. It would be interesting to further sub-divide the data , but this is not possible due to the small number of observations taken relative the the total size of the experiment (see table 1). Means and standard deviations for each group were computed for the seven days identified above. T-tests were then conducted to determine if there were any statistical differences bewteen stress index readings between the HIGH and the LOW groups. The results show that significant differences were detected on 5 of the 7 days (Table 5)

Table 5 Statistics and T-test results for stress index readings collected on 7 days during the 1988 season. The LOW group had lint yields of less than 1500 lbs/acre. The HIGH group had lint yields greater than 1500 lbs/acre.

GROUP	Date	N	Mean	std	Min	Max	T-test Value
LOW	June 29	61	2.74	1.23	0.20	7.20	8.2 *
HIGH		35	1.02	0.83	-0.40	3.70	
LOW	July 1	68	2.35	1.22	0.00	6.20	9.2 *
HIGH		75	0.88	0.52	0.10	3.20	
LOW	July 9	27	0.63	1.16	-2.50	2.80	0.93
HIGH		73	0.38	1.31	-1.60	5.60	
LOW	July 13	138	1.06	1.09	-1.20	3.60	6.44 *
HIGH		150	0.21	1.15	-2.30	3.30	
LOW	July 20	69	0.13	1.01	-2.00	2.70	2.11 *
HIGH		75	-0.22	0.98	-2.40	1.90	
LOW	July 25	69	-0.97	1.22	-4.10	1.10	2.00 *
HIGH		75	-1.35	1.04	-3.80	0.40	
LOW	Aug. 27	56	-0.11	1.95	-2.10	12.40	1.26
HIGH		53	-0.48	0.99	-2.60	2.00	

* = significant at the 0.05 level. Significance is based on a signed t-value with 25 degrees of freedom (1.708) (Table is in :Principle and Procedures of Statistics, by R.G.D. Steel and J.H. Torrie, 1960, McGraw-Hill,page 433)

Table 5 shows that areas with high lint yields had consistently lower average stress readings than those with low yields. Also, note that on 6 of the 7 days, that areas with high yields also had lower MAXIMUM index readings recorded (Table 6).

Table 6. Maximum index values observed in HIGH and LOW yielding areas.

Date	Maximum index observed in HIGH yielding areas	Maximum index observed in LOW yielding areas
June 29	3.7	7.2
July 1	3.2	6.2
July 9	5.6	2.8
July 13	3.3	3.6
July 20	1.9	2.7
July 25	0.4	1.1
August 17	2.0	12.4

These results conclusively demonstrate that stress index readings do discriminate between the stress behavior of high and low lint yielding areas in cotton. It is clear that both the average stress index and the maximum index observed provide information which should be useful to growers.

INFLUENCE OF OPERATOR ERRORS

The differences which are noted in table 5 are relatively small, generally about 1 index point, between the HIGH and the LOW areas. The basis for these relatively small differences can be traced to the fact that personnel using the Scheduler^{tm} did not consistently use proper sampling technique. This is evidenced by the standard deviation of crop temperatures they produced (Table 7). Note that the average standard deviation ranged between 0.71 and 2.38 (F) This is very high. Normal standard deviations are generally around 0.5 F or less. The standard deviation of the standard deviations ranged between 0.54 and 1.57. This number should have been around 0.1 to 0.2. Note also, the extreme standard deviations measured on each day, ranging between 2.6 and 15.9. These results strongly suggest that the instrument operator did not follow the recommended guidelines in aiming and using the Scheduler^{tm} . The effect of this problem would be to minimize differences in average index values between HIGH and LOW yielding areas. In spite of this obvious operator problem, tables 5 and 6 demonstrate that signficant differences existed in index values between the HIGH and LOW yield areas. I can only speculate that the observed differences would have been larger had the operator used a more carefully controlled sampling technique.

Table 7. Statistics for the standard deviation of crop temperatures recorded on 7 days in 1988. Temperatures were in degrees Farenheit.

DOY	N	AVG. STD (degrees F)	STD	MIN	MAX
June 29	96	2.38	1.57	1.00	15.90
July 1	143	1.94	0.73	0.70	4.90
July 9	100	0.74	0.62	0.20	3.90
July 13	288	1.03	1.09	0.10	12.60
July 20	144	0.75	0.46	0.10	2.60
July 25	144	0.71	1.09	0.10	8.90
Aug. 17	109	0.73	0.54	0.20	4.00

APPENDIX I

STEPHANIE JOHNSON 1988 HARVEST DATA (RANKED FROM LOWEST TO HIGHEST LINT YIELD)

PLOT NUM.	IRR TRT	VAR TRT	PIX TRT	SEED YIELD (LBS/A)	LINT YIELD (LBS/A)	TRT CODE	
				Low Yield Group			
128	3	1	2	3326.4	968.1	312	RANK = 1
406	3	3	2	3554.1	1095.3	332	
102	3	3	3	3791.7	1114.0	333	
306	3	1	3	3663.0	1118.7	313	
120	3	3	4	3771.9	1120.6	334	
101	3	1	4	3643.2	1151.8	314	
119	3	1	1	3534.3	1167.7	311	
324	3	1	1	3593.7	1175.1	311	RANK = 2
111	3	3	2	3999.6	1178.3	332	
333	3	1	2	3801.6	1178.5	312	
318	1	2	1	3851.1	1190.2	121	
433	3	3	4	4019.4	1191.0	334	
110	3	1	3	3712.5	1194.3	313	
129	3	3	1	3910.5	1199.9	331	
315	3	1	1	3732.3	1202.2	311	
230	3	1	1	3940.2	1214.0	311	
221	3	1	4	3989.7	1226.9	314	
405	3	1	1	3752.1	1227.8	311	
112	3	2	1	4187.7	1238.0	321	
229	3	3	3	4177.8	1238.1	333	
220	3	3	2	4197.6	1239.6	332	
211	3	3	4	4078.8	1244.6	334	RANK = 3
415	3	3	3	4158.0	1248.3	333	
420	1	2	1	4128.3	1251.6	121	
314	3	3	1	4207.5	1257.8	331	
411	1	2	3	4148.1	1260.3	123	
424	3	3	1	4049.1	1265.6	331	
332	3	3	2	4316.4	1288.7	332	
212	3	1	3	4138.2	1289.8	313	
414	3	1	4	3900.6	1291.7	314	

PLOT NUM.	IRR TRT	VAR TRT	PIX TRT	SEED YIELD (LBS/A)	LINT YIELD (LBS/A)	TRT CODE	
228	3	2	4	4415.4	1306.1	324	
219	3	2	3	4415.4	1312.0	323	
130	3	2	4	4583.7	1320.0	324	
432	3	1	2	4158.0	1323.5	312	
210	3	2	1	4504.5	1326.9	321	
236	2	3	2	4464.9	1329.5	232	
209	2	3	4	4435.2	1330.7	234	RANK = 4
423	3	1	3	3960.0	1333.9	313	
202	3	3	1	4237.2	1349.9	331	
327	1	2	1	4484.7	1364.3	121	
121	3	2	3	4534.2	1375.7	323	
304	3	2	2	4662.9	1380.7	322	
404	3	2	3	4534.2	1396.1	323	
203	3	1	2	4346.1	1397.4	312	
323	3	3	1	4761.9	1399.6	331	
334	1	1	2	4672.8	1412.1	112	
132	2	1	2	4712.4	1414.4	212	
313	3	2	1	4593.6	1415.0	321	
231	1	3	4	4949.9	1419.6	134	
336	1	2	2	4831.2	1426.3	122	
413	3	2	2	4653.0	1432.9	322	
422	3	2	4	4761.9	1437.3	324	
418	2	1	4	4346.1	1437.4	214	
201	3	2	4	4841.1	1437.6	324	
402	1	2	2	4712.4	1437.7	122	
317	1	3	1	4643.1	1454.3	131	
419	1	3	3	4841.1	1454.5	133	RANK = 5
322	3	2	1	4860.9	1458.1	321	
218	2	3	3	4781.7	1458.1	233	
311	2	1	1	4613.4	1458.6	211	
305	3	3	1	4752.0	1459.9	331	
214	1	1	3	4781.7	1477.4	113	
309	1	2	4	4851.0	1479.8	124	
412	1	1	4	4633.2	1480.5	114	
227	2	3	1	4880.7	1488.8	231	
335	1	3	2	5058.9	1491.1	132	
401	1	3	4	4761.9	1495.3	134	
103	3	2	2	5058.9	1496.4	322	
123	2	1	4	4771.8	1498.0	214	

High Yield Group

PLOT NUM.	IRR TRT	VAR TRT	PIX TRT	SEED YIELD (LBS/A)	LINT YIELD (LBS/A)	TRT CODE
427	2	1	3	4563.9	1504.1	213
403	1	1	1	4682.7	1506.1	111
430	1	1	3	4732.2	1509.9	113
222	1	3	1	5266.8	1528.0	131
223	1	1	4	4940.1	1532.4	114
426	2	3	4	5197.5	1534.3	234
330	2	3	2	5256.9	1535.9	232
134	1	3	3	5593.5	1540.1	133
431	3	2	1	5157.9	1542.5	321
407	2	2	4	5316.3	1547.3	224
325	1	1	1	4831.2	1547.7	111
316	1	1	1	4761.9	1552.9	111
436	2	1	2	4851.0	1554.1	212
435	2	3	1	5039.1	1558.4	231
232	1	1	2	4940.1	1558.9	112
118	1	3	2	5128.2	1559.6	132
105	2	1	3	5148.0	1559.9	213
421	1	1	2	4672.8	1561.3	112
410	1	3	1	5108.4	1562.8	131
429	1	2	4	4712.4	1565.1	124
331	3	2	2	5276.7	1568.3	322
307	1	1	1	4781.7	1571.7	111
409	2	1	1	4860.9	1574.1	211
417	2	3	2	5128.2	1574.2	232
136	1	3	3	5445.0	1574.9	133
127	1	3	4	5227.2	1576.9	134
434	2	2	3	5524.2	1578.8	223
329	2	1	2	4979.7	1579.9	212
117	1	1	3	5059.0	1581.4	113
204	1	3	3	5346.0	1582.5	133
308	1	3	2	5078.7	1588.5	132
326	1	3	1	5177.7	1592.1	131
131	2	3	4	5395.5	1595.1	234
205	1	1	1	5187.6	1596.5	111
213	1	3	2	5336.1	1599.9	132

RANK = 6

PLOT NUM.	IRR TRT	VAR TRT	PIX TRT	SEED YIELD (LBS/A)	LINT YIELD (LBS/A)	TRT CODE	
113	2	3	2	5266.8	1604.7	232	
408	2	3	3	5237.1	1604.8	233	
312	2	3	1	5296.5	1615.3	231	
126	1	1	1	5128.2	1616.7	111	
428	1	3	2	5306.4	1624.8	132	
425	2	2	2	5415.3	1633.3	222	
233	1	2	1	5771.7	1634.5	121	
216	2	1	2	5167.8	1644.2	212	
109	1	3	1	5217.3	1645.1	131	
108	1	1	2	5078.7	1652.0	112	
234	2	1	3	5237.1	1659.5	213	
116	1	2	4	5445.0	1659.6	124	
116	1	2	4	5445.0	1659.6	124	
116	1	2	4	5445.0	1659.6	124	RANK = 7
206	1	2	3	5692.5	1662.3	123	
135	1	1	4	5316.3	1667.5	114	
107	1	2	2	5781.6	1675.5	122	
303	2	3	3	5385.6	1676.2	233	
319	2	2	1	5781.6	1679.7	221	
122	2	3	3	5623.2	1680.0	233	
235	2	2	4	5910.3	1685.1	224	
302	2	1	1	5177.7	1685.4	211	
125	1	2	1	5326.2	1692.1	121	
104	2	3	1	5603.4	1695.6	231	
224	1	2	2	5801.4	1700.9	122	
328	2	2	2	5781.6	1703.4	222	
215	1	2	4	6019.2	1713.9	124	
320	2	1	1	5148.0	1725.7	211	
207	2	1	4	5534.1	1727.7	214	
321	2	3	1	5860.8	1739.3	231	RANK = 8
225	2	1	1	5623.2	1745.3	211	
416	2	2	1	5930.1	1770.7	221	
106	2	2	4	6147.9	1775.7	224	
217	2	2	1	6276.6	1776.2	221	
226	2	2	3	6138.0	1783.1	223	
124	2	2	2	6058.8	1790.0	222	
301	2	2	4	5989.5	1840.5	224	
133	2	2	1	6009.3	1861.8	221	RANK = 9
310	2	2	1	6345.9	1880.9	221	
208	2	2	2	6603.3	2149.8	222	RANK = 10

TREATMENT CODES

PLOT= PLOT NUMBER

IRR=IRRIGATION TRT 1=-15,-16 = 15 BARS AT FIRST IRRIGATION
16 BARS ALL OTHER IRRIGATION

2=-15,-18 = 15 BARS AT FIRST IRRIGATION
18 BARS ALL OTHER IRRIGATION

3= -18,-18 = 18 BARS AT ALL IRRIGATIONS

VAR=VARIETY CODE 1=GC-510 2= SJ-2 3=GC-356

PIX=PIX CODE 1=CONTROL
2=1/2 PINT PIX AT 1ST BLM
3=1/8 PINT PIX AT MH SQUARE ,1/4 PINT AT FIRST
4=1/4 PINT PIX AT MH SQUARE, 1/2 PINT AT FIRST

YIELD=SEED COTTON YIELD (LBS/ACRE)

LINT=LINT YIELD (LBS/ACRE)

TRT= 3 DIGIT NUMBER FOR TRT 1ST =IRR 2=VAR 3=PIX
FOR EXAMPLE IF TRT=124 THEN IRR=1 VAR=2 AND PIX=4

March 5, 1988

SIGNS OF STRESS

Rule No. 1: Don't overstress your cotton at the early stages. Rule No. 2: Know how much water your variety needs.

by Alton Pryor

Growers may be overstressing their cotton in their attempts to get heavier fruit set, especially during the bloom period. This is borne out by two years of study by Tulare County farm adviser Stephanie Johnson.

Johnson initiated her irrigation experiments in 1985 when growers complained that the newly released Germains GC-510 variety did not tolerate stress as well as Acala SJ-2, which is considered the standard variety for the San Joaquin Valley. "The question is, When we have new varieties that become available, which is not that often, do the recommendations previously prescribed meet the water requirements of the new varieties?" asked Johnson.

Three different irrigation treatments were established on SJ-2, SJC-1, and GC-510, the predominant cotton varieties grown in the SJV. One treatment was to irrigate so that the plant was not stressed at all; the second used the normal practice of moderately stressing the plant; and a third placed the cotton plant under severe stress.

A pressure bomb, which measures leaf water potential in units called bars, was used to determine when the various plots would be irrigated. The nonstressed plots were irrigated when leaf water potential reached -15 bars; the moderately stressed plots were irrigated at -19 bars; and the severely stressed plants were irrigated at -23 bars.

Johnson based her experimental strategy on research conducted by Don Grimes, a UC irrigation specialist at the Kearney Agricultural Center in Parlier. Grimes had found that the cotton plant's main stem growth and elongation proceed at a normal rate when leaf water potentials are near -11 bars shortly after an irrigation. His tests also showed that growth essentially ceases when leaf water potentials reach -24 bars.

"It is of interest to note that over the course of the season, mean leaf water potential readings for the three varieties were significantly different, and these differences were not affected by irrigation," Johnson said. Acala SJ-2, she found, had the highest mean seasonal reading of -15.6 bars, followed by SJC-1 (-15.2 bars), and GC-510 (-14.8 bars).

PHOTO BY ALTON PRYOR

Farm adviser Stephanie Johnson found that all three varieties she tested yielded best with early irrigations, even though less-determinate varieties are under less stress. "Yields tended to decrease with increasing water stress," she says.

"This would indicate the more determinate varieties [GC-510 and SJC-1] are under less plant-water stress," the farm adviser explained. "The reasons for this are uncertain, but one theory suggests that varieties such as SJC-1 and GC-510 have more extensive rooting systems and less leaf area. With a greater root-to-shoot ratio, these plant types may be able to mine water from a greater soil area."

Flower counts were also taken during bloom period to determine whether varying the first irrigation application would alter the rate of flowering. Flowering rates were also significantly different among the three varieties when evaluated over the season.

With an early first irrigation, SJ-2 achieved peak bloom earlier than the other varieties. When the first irrigation was delayed, the more determinate varieties (SJC-1 and GC-510) produced a greater number of blooms early in the season and also cut out earlier regardless of subsequent irrigations. SJ-2 was somewhat more forgiving of stress and was able to compensate with continued growth over a longer period of the season, Johnson reported.

Johnson also found that the best yields were obtained for all three varieties when the first irrigation was applied early. "Yields tended to decrease with increasing water stress," Johnson pointed out. "The late irrigation was extremely detrimental to yield for all varieties."

Based on her first year's test results, Johnson said that early growth is reduced when the first irrigation is delayed too long. The plants are unable to recover and, as a result, produce fewer fruiting positions. Plants that received the earlier irrigation produced approximately 18 percent more fruit positions than did the severely stressed plants. With early irrigation, Acala SJ-2 yielded 1740 pounds, and SJC-1 yielded 1660 pounds.

In 1987, Johnson's trials assessed the effect of stress on optimum irrigation schedules for SJ-2 and GC-510. They showed that the highest SJ-2 yields came with the first irrigation at -18 bars and the second at -16. But since yields ran a close second when irrigating first at -15 and then at -18 (one irrigation must be at -18), she says, SJ-2 showed great flexibility in irrigation timing.

For GC-510, though, the first irrigation is critical and must be done at -15 bars. Any earlier or later, Johnson explains, showed reduced yields. The second irrigation's timing, however, is more flexible, and may be done at either -18 (the highest yields) or -16 (a close second).

Several methods are available for measuring plants' water needs. These include the neutron probe, soil tensiometers,

Continued on page 25-E

STRESS
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the pressure bomb, and, newer on the market, infrared thermometers.

Lacking these instruments, growers can tell a great deal about their irrigation needs by checking the soil and carefully observing the plants themselves. For instance, checking the soil below the surface to determine if it is dark in color, if it stains the hand, and if it forms a ball or ribbon when squeezed are all indicators of moisture content.

With a vigorously growing cotton plant, Johnson pointed out that the upper portion of the main stem remains green while the lower stem stays reddish. As the plant is stressed for water, vegetative growth slows, and the red coloration moves closer to the growing tip. According to Johnson, some growers like to use this color difference for irrigation management by applying water when the red portion is within 3–4 inches of the growing tip.

Johnson cautioned, however, that this strategy will not work on a crop that has been treated with Pix because the red coloration will generally remain within 2 inches of the growing tip. Also, with the newer GC-510 variety, this color change does not occur when the plants are water stressed.

Another sign growers can watch for is wilting. While plants will normally wilt to some degree on hot afternoons, Johnson warned that if wilting is noted around noon, water is needed soon. If wilting is noted before noon, cotton yields have already been affected.

Another good method for determining water needs is the use of the water budget system, very similar to keeping a bank account. "Think of the root zone reservoir as your initial bank account balance," Johnson advised. "A thorough wetting of the soil, either by winter rains or a preplant irrigation, will bring this soil reservoir up to full capacity. Water is withdrawn from this account daily, mainly through evapotranspiration or transpiration from the leaves."

To use this method, the grower needs to know the water-holding capacity for a particular soil. This information is available from local farm advisers, the state Department of Water Resources, or the Soil Conservation Service. By correlating this information with evapotranspiration rates, which are published in many local newspapers, a grower can determine how much water has been spent from his budget and make arrangements to replenish it.

Tomato Growers Had a "Fantasy" '87

The tomato industry's performance in 1987 would have seemed "pure fantasy" a year ago, according to David Zollinger, executive vice-president of the California Tomato Growers Association, but "an unplanned bumper crop, grown and harvested under ideal conditions," combined with strong demand from processors to produce a bright year for growers.

What's more, "strong movement of the '87 pack, with spot shortages of certain styles and container sizes," suggest that some processed-tomato items may be out of stock before the 1988 harvest, added Zollinger, who spoke at CTGA's annual meeting in Sacramento on Jan. 28. "This goes a long way to explain the strong interest by processors in '88 contracts." Processor demand is now in the range of "6.5 million tons and building," Zollinger added.

One reason for the improved outlook was the sharp drop in imports of processed tomato products. Imports were down 32 percent last year from their peak in 1983–84, permitting domestic producers to sell another 250,000 tons to U.S. processors.

CTGA's cash price objective for 1988 is $48, compared to a market basket price of $46.50 for the first six months of the 1987–88 marketing cycle. The most recently reported month, December 1987, showed a base price higher than $46.50, leading Zollinger to conclude that, with higher processor demand, reduced imports, and higher labor costs to growers as a result of the increase in the state minimum wage, "CTGA's cash price objective of $48 is quite reasonable."

Zollinger also noted progress on A.B. 2642, a bill sponsored by Assembly Speaker Willie Brown that would authorize mediation of disputes between bargaining associations like CTGA and processors when there is an impasse. It passed the Assembly in January.

—Richard Smoley

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COMPARING SCHEDULER^R READINGS WITH LEAF WATER POTENTIAL MEASUREMENTS

Two experiments have been conducted to determine the relationship between cotton stress index values and leaf water potential measurements. The first study was conducted by the USDA in 1984 at the Westside field station near Five Points, California. They found the following relationship:

$$LWP = 15.2 + 1.28 * \text{Stress Index}, \quad (R^2 = 0.66)$$

In 1986, Lowell Zelinski, University of California Extension in Fresno, found the following:

$$LWP = 14.92 + 1.15 * \text{Stress Index}, \quad (R^2 = 0.61)$$

Although these two equations are virtually identical, this does not mean a user should expect these equations to predict an exact value of LWP for a given Scheduler^R reading. Predictions based on these equations may have a range of $\pm$ 4 bars.

Several factors could cause predictions of LWP measurements based on Scheduler^R readings to differ from measured values by other users.

a. These equations were developed for the most recently fully expanded leaves (usually the third or fourth from the apex). Others may sample different leaves.

b. Variation among users in determining the end-point. Apparently the USDA and University of California researchers had similar end-point techniques. Determination of an end-point is an art (usually consistent for a given user) but can vary greatly between users.

c. Influence of crop growth stage on Scheduler^R readings. The above equations are average trends for a season. These equations probably are not constant throughout a season, but are a function of percent ground cover and age of the crop.

d. Influence of the environment on LWP readings. Theoretical equations have been developed which show that LWP is a function of environmental conditions.

e. Influence of sample size. LWP readings are made on single leaves. Scheduler^R readings encompass a canopy.

F45 Bronson

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Dear Clint:

Please excuse me for not getting my comments regarding this manuscript back to you sooner. We had annual reports to get written and a presentation for our station advisory committee to prepare, and my review of this paper just kept getting shoved back.

Most of my comments are on the manuscript, but let my go through some of them in more detail.

1. I still believe that this paper would serve a better purpose by being published in Applied Agricultural Research or Journal of Production Agriculture. The readership of these two journals would greatly benefit from the experiences and tutorial-type information reported.

2. The paper is quite lengthy, and you should consider attempting to split it into two companion papers if possible. My suggestion would be to have the first paper deal with history, theory, and baselines, and have the second paper deal with sampling procedures, routine use, and interpretation. Of course, this would require separate introductions and summaries be written for both papers.

3. I think the paper will read better if the frequent references to the Carborundum experience are removed. Not every experience reported in this manuscript is unique (or proprietary) to the Carborundum Company. Both you and I and many others working with infrared thermometry have had similar experiences.

4. The discussion of the change in CWSI scale by a factor of 10 is too lengthy. It probably is enough to say that in transferring this technology to producers and growers, changes in magnitude on a scale of 0-10 are more easily understood than on a scale of 0-1.

5. The paper has many errors in literature citations, some cited incorrectly in the text, and some not appearing in the reference list. These need to be checked thoroughly.

6. The terms "moisture stress" and "water stress" are used interchangeably throughout the paper, but you should be consistent and use just one. I prefer water stress.

7. Figure 2 needs more detail to be easily understood.

8. Equations are not numbered correctly.

9. References are needed to support the statement that "Several techniques exist in the literature for estimating MAX." There definitely needs to be a discussion regarding Idso's definition of MAX which floats with ambient air temperature, and why it is preferable to define MAX which does not change.

10. There is no discussion about how the CWSI trend curve (Fig. 3) is derived.

11. Fig. 4 is does not add much to the discussion of different classes of crops having different levels of stress tolerance. I would delete it.

12. I don't think that the lengthy discussion and derivation to show how leaf water potential is influenced by the same environmental parameters as CWSI is appropriate for this paper. I would rather replace this whole section with a review of literature which documents the number of studies showing relationships between CWSI and leaf water potential, stomatal conductance, leaf photosynthesis, leaf transpiration, and available water in the active root zone.

13. I don't understand what is meant by the "specific calculation procedures used in the Scheduler" which are proprietary. Isn't the actual calculation procedure just the equation given earlier in the manuscript? There is probably no benefit to this manuscript in making a point that the Carborundum has proprietary, unavailable information. If there is a point that I am not getting from this paragraph, then it needs to be rewritten more clearly.

14. I have some question regarding the statement made in point j. of the Sampling Guidelines discussion. In large fields you would not be out of the fully adjusted boundary layer even at two meters above the crop canopy. That is not to say that there aren't significant gradients of temperature and humidity within and above crop canopies, but my experience has been that there have been no problems when measuring within 1 m of the top of the crop canopy. In fact, when we have measured single leaves using an IRT within a few centimeters of a leaf, right on top of the canopy, we still get very good results. I would like to hear more about what your experience with these types of measurements have been.

There is a lot of valuable information and experience in this paper, and I look forward to seeing it in print. Please let me know if you have questions about my comments, and if there is anything you would like me to do.

Sincerely,

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cc: Bronson R. Gardner